GROWTH RETARDATION OF MOCKORANGE HEDGE, *Murraya paniculata* (L.) Jack, BY DIKEGULAC-SODIUM

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN HORTICULTURE

AUGUST 1981

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Appendix Figure

INTRODUCTION

Mockorange, Murraya paniculata (L.), is widely used as a hedge plant in Hawaii for private homes, parks, and highways to divide or conceal one area from another. One of the problems of this hedge is its high rate of growth which requires frequent trimming and resulting high costs of maintenance. One solution may be the use of growth regulators. Proper use of growth regulators may suppress the growth of the hedge for a period of time without noticeable abnormal symptoms and thereby reduce the number of trimmings.

Previous studies on mockorange (Griset, 1970 and Criley, 1980) reported a large variance in the hedge growth and in the useful ranges of concentration for some growth regulators. But their results were not conclusive, and the information was insufficient for using a growth regulator to suppress the growth of a mockorange hedge. Therefore, the purpose of this study was to solve some problems in the use of a growth regulator, so that one could effectively control hedge growth. The problems to be solved were; effect of seasons, effect of stage of growth at the time of application, effect of vigor of the plant, effect of shade, and duration of time necessary for foliar absorption on plant response to a growth regulator.

LITERATURE REVIEW

A. Chemical control of hedge growth

Problem of overgrowth

Excessive growth of woody species in the landscape has been a problem. Reducing plants size under power lines is costly in Ohio (Kozel et al., 1980), pruning trees along streets is hazardous in California (Sachs et al., 1970, and trimming hedges is costly in Hawaii (Criley, 1980).

Proper selection of species usually minimizes the problem, but sometimes plants already exist and, for hedges, regular trimmings are desired. Traditionally, physical pruning has been the solution to the problem.

Since 1950 when 6-hydroxy-3-(2H)-pyridazinone (maleic hydrazide) was introduced (Smith et al., 1950), researchers have sought for chemical methods of retarding growth of plants. Cathey (1964) summarized the physiological properties of 8 types of growth retardants and he (1975) also conducted extensive research on growth retardation of potted plants for nursery operations. For woody species, maleic hydrazide (Sachs and Maire, 1967; Sachs et al., 1970), butanedioic acid mono(2,2-dimethyl= hydrazide)(daminozide) (Sachs and Maire, 1967), and methyl 2-chloro-9-hydroxy-fluorene-9-carboxylic acid (morphactin) (Kozel et al., 1970) were found to be effective. Then, Sachs and Hackett (1972) reviewed research on chemical control of plant height. They listed 7 factors which determine the use of chemicals: 1) identifying the primary cause of inhibition of stem elongation; 2) timing the application of compounds to the appropriate stage of plant development; 3) determining the best method of application ; 4) determining the optimum dosage, formulation,

and frequency of application; 5) testing for cumulative phytotoxicity; 6) noting species specificity; and 7) taking note of potential environmental effects. Recent experiments have mainly focused on method of application: injection (Brown et al., 1977; Roberts et al., 1979; Ufferman et al., 1979), bark application (Kozel et al., 1970; Backhaus et al., 1976), the comparison of application methods (Hield et al., 1977; Domir, 1978). Other aspects studied were formulation (Sachs et al., 1975) and effect of geographical location (Roberts et al., 1979), as well as testing of new chemicals.

Topics in chemical control of hedge growth

1) Mechanism of control

Sachs and Hackett (1972) separated the mechanisms of growth control into 3 groups: a) Death of the terminal buds of branches or severe inhibition of apical meristematic activity. Chemicals with this mechanism action were maleic hydrazide, morphactin, (2-chloroethyl)phosphonic acid (ethephon), 2,3,5-triiodobenzoic acid (TIBA), and methyl ester of fatty acid; b) Inhibition of internode elongation without disruption of apical meristematic functions. Chemicals with this mechanism of action were daminozide, N,N,N,2-tetramethyl-5-(1-methylethyl)-4-(1-piperidinyl-carbonyl)-oxy benzenaminium chloride (Amo-1618), (2-chloroethyl) trimethylammonium chloride (chlormequat), and tributyl (2,4-dichloro-benzyl)-phosphonium chloride (CBBP); c) Reduction of apical control. Chemicals with this mechanism of action were ethephon and maleic hydrazide when applied at low concentrations. The sodium salt of 2,3:4,6-di-O (1-methylethylidine)-L-xylo-2-hexulofuranosonic acid (dikegulac-sodium) probably retards shoot elongation through the third mechanism, reduction of apical control, since it did not kill terminal buds (Sachs et al.,

1975) or inhibit gibberellic acid synthesis (Bocion and de Silva, 1976), while it reduced apical dominance (de Silva et al., 1976b).

2) Timing of the application

Generally, growth inhibitors which kill apical meristems should be sprayed after stem elongation to allow some of new leaves to expand. On the other hand, growth retardants which inhibit internode elongation were more effective when applied before stem elongation occurs (Sachs et al., 1970). There is no generalization for the third type of mechanism, but a spray of dikegulac-sodium before leaf expansion reduced phytotoxicity on leaves (Sachs, et al., 1975).

3) Methods of application

Spraying is the most common method of applying growth regulators. Its effectiveness is subject to many factors: local environment such as high relative humidity in greenhouse and geographical location (Sachs and Maire, 1967); seasons (Sachs and Maire, 1967); stage of leaf growth (Sachs et al., 1970); droplet size (Cathey, 1975); and nature of cuticle (Franke, 1967). The advantages are uniform coverage and no wound on trees. The disadvantages are a relatively high cost, the difficulty of application when plants are large, hazards to the environment by drift, and the requirement for a leaf surface to receive the spray.

A soil drench may be used for container-grown plants if the growth regulator is easily absorbed and translocated (Cathey, 1975). However, because of potential hazard to the environment, this method is not generally suitable for field application.

Bark dressings were applied through cuts on the trunk (Kozel et al., 1970) or to the bark (Backhaus and Sachs, 1976). The advantages of bark dressings were no drift, only a small amount of chemical per tree, no

heavy equipment, and rapid application. Effectiveness of the chemicals was enhanced by using gauze around the trunk (Backhaus and Sachs, 1976) and diesel oil as the carrier (Hield et al., 1977). This was probably because compounds were protected from drying. The disadvantages were that the bark was difficult to penetrate because of its physical and chemical composition and application could result in abnormal development of cambium tissue (Domir, 1978).

Recent techniques have permitted injection of growth regulators into trunk with pressure (Hield et al., 1977) and without pressure (Roberts et al., 1979, and Ufferman et al., 1979). The advantages were no drift, only a small amount of growth regulator per tree was necessary, and precise dosages could be injected. The disadvantages were the wounding of the trunk and requirement of heavy equipment for high pressure injection.

Cut painting was done by applying a growth regulator to the pruned surface of tree limb (Hield et al., 1977). It was more effective when asphalt was used as the carrier of the growth regulator than without a carrier, but the effect was limited to within 60 centimeters from the treated area.

Considering these methods of application, spraying a growth regulator at the right time with the right concentration is the most practical method for hedges when drift is properly controlled because a soil drench may be hazardous to the environment, bark dressing and injection are not developed sufficiently for practical use at this time, and cut painting is unpractical for hedges. But, bark dressing with proper methods and equipment could be a potential way of controlling hedges.

4) Number of applications

Using multiple spray applications of a low concentration has advan-

tages over a single application of high concentration. Greater retardation was obtained (Sachs and Maire, 1967), and toxic symptoms were less on leaves (Sachs et al., 1970). But, the cost of application is multiplied by the number of applications. For hedges in subtropical environments where plants grow almost year around, multiple applications could just be repeats of a single application.

5) Surfactant

Responses of plants to growth regulators are not only affected by the concentration but also by the surfactant employed. Surfactants increased the effectiveness of maleic hydrazide (Sachs and Maire, 1967; Sachs et al., 1970) and reduced phytotoxicity on leaves (Sachs et al., 1975). Sachs and Hackett (1972) stated that "above 0.1 percent most surfactants inhibit growth and cause foliar damage on many species" when they were sprayed to run-off. Surfactants could be modifying leaf surface and causing changes in endogenous hormones.

6) Specificity of response

Cathey (1975) reported a differential response of 88 ornamental species to 5 growth retardants. Specificity was also found in shrubs (Sachs et al., 1975) and trees (Brown et al., 1977). Sachs and Hackett (1972) described the specificity on the basis of ease of absorption, rate of transport and cell sensitivity. Future research could be done by actual concentration of growth regulators taken up by cells to reduce large variance between plants instead of the concentration applied externally.

7) Evaluation of hedge quality

Sachs et al. (1970) introduced a concept of near landscape and distant landscape. When plants are viewed from more than 25 feet, all that

observers can perceive is the general color of the plants while damage to terminal buds and unexpanded leaves is rarely noticed. This distant landscape concept can be applied to the plantings along highways or streets. But, if plants are viewed closely such as for a hedge around the house or garden, one additional standard should be that plants are retarded without showing abnormal symptoms.

Brown et al. (1977) reported that measured regrowth of topped American elm (Ulmus americana) and American sycamore (Plantanus occidentalis) had skewed distribution to the left. But, when each tree was considered as an experimental unit, the mean number of sprouts per tree was approximately normally distributed as was the mean length of the longest sprout. They also indicated that the longest upright branch on a tree determined the clearance for the tree under a power line. This could be applied to hedge growth. When a hedge is viewed, some long branches are usually the most conspicuous, and most of the branches are not recognized because they are hidden in a mass of leaves. The decision as to when a hedge should be trimmed is made not only by the height of regrowth but also by the evenness of the hedge surface. Therefore a desirable quality of growth regulator application to hedges in near landscape is not only to retard the regrowth but also to allow even regrowth without visible abnormal symptoms.

B. Mockorange

In Hawaii, mockorange is a common name for Murraya paniculata (L.) Jack, synonym of M. exotica L. The plant is also called orange jasmine or, in Hawaiian, alahe'e-haole or walahe'e-haole. The plant is classified in the Rutaceae family and can be described by 1) tree or shrub, 2) fruit juicy, globose or ovoid, 3) leaves compound, 4) leaflets 2 to 9,

pinnately arranged, and 5) fruit red (Neal, 1965). Leaves usually have single terminal leaflets. The genus Murraya was named after the Swedish botanist Johann Andreas Murray (Georke, 1976).

Neal (1965) described this plant as "The mockorange may become a tree 20 feet high, but ordinarily is a shrub 6 to 8 feet high. It is ornamental only, its half-inch-long, red, one- to two-seeded berries being inedible. Because of its dense, rich-looking, shiny foliage, which consists of small leaflets, three to seven to a leaf, and its sweet, white, five-parted flowers, which commonly appear between June and September and in midwinter in Hawaii. The shrub is popular in many warm countries and often serves as a hedge."

Chemical growth retardation of the plant was studied by two researchers. Griset (1970) applied 16 growth retardants on young seedlings in greenhouse, and found maleic hydrazide to be the most effective at a concentration of 1,500 ppm or higher. He also applied 2 growth retardants on mature hedge to test their effectiveness, but he could not get significant results due to 1) irregular growth pattern within the hedge, 2) seasonal differences in growth, and 3) poor selection of the sections in the hedge. Criley (1979) applied 5 growth regulators and some combinations on mature hedges in the field including dikegulac-sodium. He reported all treatments were effective in retardation, and choice should be made with regard to the phytotoxicity.

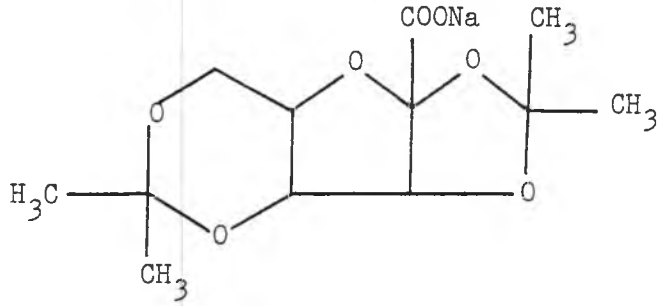
C. Dikegulac-sodium

Chemistry

The sodium salt of 2,3:4,6-di-O(1-methylethylidine)-L-xylo-2-hexulofuranosonic acid (dikegulac-sodium) is one of the newest growth regulators being examined for their growth retarding property on woody plant

Table 1

Some properties of dikegulac-sodium

Common name:	dikegulac-sodium (provisionally approved by ISO)
Chemical name:	sodium salt of 2,3:4,6-di-O(1-methylethylidine) -L-xylo-2-hexulofuranosonic acid
Synonym:	sodium 2,3:4,6-di-O-isopropylidine-2-keto-L-gluconate
Commercial name:	Atrinal
Molecular weight:	296
Form and color:	White and odorless solid, with a melting point above 300°C.
Stability:	In a dry state is it stable for at least three years stored at room temperature. Stable in aqueous solutions at pH7 and above. Slowly hydrolyzed under acidic conditions, more rapidly at pH5 and below. Not light sensitive.
Solubility at 25°C:	water 59% w/w methanol 39% w/w ethanol 23% w/w chloroform 6% w/w acetone, cyclohexane and hexane less than 1% w/w
Structure:	

species. The growth regulator was first described by Bocion et al. (1975), who reported that it retarded growth in a wide range of plants, overcame apical dominance, stimulated ripening of fruit, induced abscission of fruit, and enhanced parthenocarpic fruit formation.

The growth regulator was an intermediate of the commercial synthesis of L-ascorbic acid. The structure is shown in Table 1 together with other properties released in a Technical Data Sheet (Anonymous, 1979). It has a monosaccharide backbone with 2 rings attached on both sides. Two oxygens on the rings are blocked by large isopropyl groups which are responsible for the hydrophobic nature of the rings. The only hydrophilic site is the carboxyl group attached on number two position of the structure. As a whole, the growth regulator has a hydrophilic carboxyl head and large rings of hydrophobic tail.

The growth regulator was tested with several salt forms and esters. Salt forms were generally more effective than ester forms and sodium salt was the best in the salt forms. Salt forms were applied as aqueous solutions, while esters were applied as wettable powders.

The commercial formulation is a liquid concentrate containing 200 grams of active ingredient per liter. X-77, a surfactant containing polyoxyethylene nonyl phenol plus free fatty acids and isopropanol, is incorporated in the formulation at the rate of 0.1 percent.

Biological activity of dikegulac-sodium

Arzee et al. (1977) observed the effect of dikegulac-sodium within cells using microautoradiography with ^{3}H labeled thymidine. DNA synthesis of Zinnia at the shoot apex was inhibited by the growth regulator and the normal zonation was lost. In Helianthus annuus, cells at the quiescent center disintegrated. Gressel and Cohen (1977) reported that

incorporation of ^{3}H uridine into chloroplast RNA of Spirodela oligorrhiza was inhibited by the growth regulator to a greater degree than into cytoplasmic RNA. They indicated that the inhibition was the result of the primary action of the growth regulator.

Zilkah et al. (1977) found differences in susceptibility of cultured cells to the growth regulator according to their stage of growth. Using a cell suspension culture of Solanum nigrum, Zilkah and Gressel (1978) showed that the growth regulator inhibited leucine uptake more in actively dividing cells than in expanding cells. A low level of the growth regulator (0.2 mM) inhibited more than 50 percent of leucine uptake by actively dividing cells, but higher levels of the growth regulator (more than 1 mM) were needed to inhibit leucine uptake in expanding cells. They also found that the effect of the growth regulator was rapid: inhibition of leucine incorporation was observed within an hour.

The rapid effect led to further studies of the growth regulator. Zilkah and Gressel (1979) conducted a kinetic study of the growth regulator using cell suspension cultures of Solanum nigrum. Cells were stained by fluorescein diacetate (FDA) and leakage of FDA from cells were measured by the spectrophotometer. The Michaelis-Menten constant for 10 mM of the growth regulator was about half of that for 6 mM. The rate of leakage was less with expanding cells than actively differentiating cells. The uptake of leucine by cells and incorporation of leucine into polypeptides were also studied using actively dividing cells. The growth regulator inhibited both, but there was a difference in time when the effects became apparent. Leucine uptake was inhibited immediately after addition of the growth regulator; however, leucine incorporation was inhibited 10 minutes later. Therefore, they concluded that the primary action or very

close to primary action of the growth regulator was to disturb the cell membrane integrity.

Zilkah and Gressel (1980) observed leakage of FDA from cultured cells by the growth regulator under microscope, and found that FDA leakage occurred much earlier than visible damage to the cells, and that the plasmalemma was more susceptible than tonoplast.

Therefore the growth regulator caused changes in the plasmalemma and inhibited nucleic acid synthesis. The response of cells to the growth regulator was different with stage of growth; actively dividing cells were susceptible at lower concentrations than were expanding cells.

Interaction with hormones and translocation

Bocion et al. (1975) associated induction of leaf abscission and stimulation of fruit ripening caused by dikegulac-sodium with ethylene biosynthesis. Bocion and de Silva (1976) reported that 1 mM of the growth regulator increased ethylene biosynthesis of pea (Pisum sativum) seedling 6-fold. It was suggested (Zilkah and Gressel, 1979) that stresses on cells caused by the growth regulator increased ethylene biosynthesis and, in turn, inhibited growth of pea seedlings.

Indoleacetic acid (IAA) retarded ethylene biosynthesis in pea seedling stimulated by the growth regulator. IAA also reversed an increase in number of lateral shoots caused by the growth regulator in azalea (Rhododendron sp.) (Bocion and de Silva, 1976). In those experiments the growth regulator acted as an antagonist to IAA.

Gibberellic acid (GA_3) reversed growth retardation caused by the growth regulator in wheat, dwarf pea, and Avena sativa (Bocion and de Silva, 1976). A low concentration of the growth regulator (0.001 mM) promoted callus growth of Lycopersicon esculentum and had a synergistic

effect with GA_3 while a high concentration (1 mM) inhibited the growth promotion caused by GA_3. Therefore the growth regulator is antagonistic to GA_3 in growth promotion but could be synergistic at a low concentration.

Kinetin at 2,000 ppm promoted branching of azalea initiated by the growth regulator (Bocion and de Silva, 1976) and maintained chlorophyll integrity in detached leaves of Avena fatua which was susceptible to degradation following treatment by the growth regulator (Purohit and Chandra, 1980). But a direct effect of cytokinin on the growth regulator is unknown since these effects could also be explained by the interactions of the growth regulator with auxin and abscissic acid respectively.

Foliar applications of the growth regulator showed both basipetal and acropetal movement in Chrysanthemum morifolium (Bocion and de Silva, 1976). The amount of the growth regulator translocated to the shoot apex was small, 0.003 percent of the total amount applied, but the translocation was detectable within a day in Zinnia sp. (Arzee et al., 1977). The latter experiment also showed that the growth regulator caused the same result as a manual pinching; they promoted axillary bud development.

Therefore a possible mechanism of action of the growth regulator is that the growth regulator applied to the leaves is translocated to the apical meristem and inhibits cell elongation by interacting with gibberellic acid while a small amount of the growth regulator inhibits cell division at the shoot apex which results in reduction of auxin biosynthesis and apical dominance.

Retardation of growth

Since Bocion et al. (1975) studies using dikegulac-sodium were conducted on growth retardation of various types of plants: shrubs and hedge plants (Sachs et al., 1975; de Silva et al., 1976; Cohen, 1978b; Criley, 1980); tree species (Hield et al., 1978; Ufferman et al., 1979); turfgrasses (Nielsen and Wakefield, 1975; Jagschitz, 1975 and 1976; Jagschitz and Barrett, 1976; Kaufmann, 1976; Watschke et al., 1976; Parups and Cordukes, 1977; Schmidt and Bingham, 1977); and flowering ornamentals (Hanks and Menhenett, 1978). Dikegulac-sodium was found to be effective on most of the plant species tested (Table 2). Spraying was the only method of application used for all experiments and dosage varied from 500 ppm to 10,000 ppm.

The growth regulator was effective for a relatively long period of time. Sachs et al. (1975) reported stem elongation was inhibited for more than 3 months in 4 species, while de Silva et al. (1976) reported 8 species were retarded for 1 growing season (4 to 6 months). Effectiveness of the chemical differed among genera, species within genus, and locations for the same species (de Silva et al, 1976b).

Even though no comprehensive study has been done, 46 species of landscape plants are listed in the manufacturer's Technical Data Sheet (Anonymous, 1979) for the use of the growth regulator in the United States. They are divided into three groups according to susceptibility to the chemical with effective concentration ranges from 780 to 6,200 ppm active ingredient. In the United Kingdom, 1,000 to 2,000 ppm of the chemical is recommended for Ligustrum spp. (Weed Control Handbook, 1977).

Growth retardation of tree species using the growth regulator is summarized in Table 3. Since trees are difficult to cover by sprays

Table 2

Growth retardation of hedge plants by dikegulac-sodium sprays

Species	Concentration ppm	Retardation of stem growth (%)	Weeks after spray	Location
Berberis thunbergii	2,000	58	16	Switzerland[1]
Callistemon citrinus	5,000	58	8	California[2]
Carpinus betulus	5,000	69	12	Switzerland[1]
Chamaecyparis pisifera	2,000	78	24	Japan[1]
Cotoneaster pannosa	5,000	99	8	California[2]
Crataegus oxyacantha	2,000	89	16	Switzerland[1]
Cupressus sempervirens	1,000	85	40	Spain[1]
Euonymus japonicum	2,000	84	24	Japan[1]
Ligustrum japonicum	2,000	86	24	Japan[1]
Ligustrum japonicum	3,000	100	9	North Carolina[3]
Ligustrum ovalifolium	1,000	75	16	Switzerland[1]
Ligustrum ovalifolium	1,400	82	14	United Kingdom[1]
Lugustrum vulgare	4,000	54	4	Switzerland[4]
Murraya paniculata	7,500	67	6	Hawaii[5]
Nerium oleander	5,000	98	8	California[2]
Nerium oleander	5,000	55	6	Hawaii[5]
Osmanthus heterophylla	3,000	29	9	North Carolina[3]
Pyracantha coccinea	3,000	74	9	North Carolina[3]
Pyracantha coccinea	5,000	99	8	California[2]
Thuya fastigiata	1,000	80	14	Switzerland[1]
Xylosma congestum	5,000	99	8	California[2]

[1] de Silva et al., 1976b
[2] Sachs et al., 1975
[3] Cohen, 1978
[4] Bocion et al., 1975
[5] Criley, 1980

Table 3

Growth retardation of tree species by dikegulac-sodium

Species	Concentration	Retardation of stem growth (%)	Weeks after application	Method of application
Acacia longifolia	3,000 ppm	0	4	spray[1]
Acer saccharinum	200 ppm	78	8	injection[2]
Alnus rhombifolia	3,000 ppm	16	17	spray[1]
Carya illinoensis	2,500 ppm	8	36	spray[3]
Ceratonia siliqua	3,000 ppm	71	8	spray[1]
Eucalyptus globulus	50 %	11	8	bark banding[1]
Eucalyptus globulus	9,000 ppm	56	8	injection[4]
Ficus nitida	50 %	26	20	bark banding[1]
Fraxinus uhdei	3,000 ppm	94	30	spray[1]
Fraxinus uhdei	9,000 ppm	82	8	injection[4]
Malus sylvestris	6,000 ppm	39	4	spray[5]
Morus alba	3,000 ppm	91	9	spray[1]
Pinus radiata	50 %	19	13	bark banding[1]
Platanus occidentalis	1,000 ppm	42	8	injection[2]
Platanus occidentalis	9,000 ppm	51	8	injection[4]
Quercus rubra	75,000 ppm	29	8	injection[4]
Schinus molle	3,000 ppm	8	24	spray[1]
Ulmus parvifolia	3,000 ppm	71	20	spray[1]
Ulmus parvifolia	50 %	12	26	bark banding[1]
Ulmus pumila	3,000 ppm	98	22	spray[1]
Vitis vinifera	1,000 ppm	58	4	spray[5]

[1]Hield et al., 1978
[2]Ufferman et al., 1979
[3]Malstrom et al., 1977
[4]Roberts et al., 1979
[5]Bocion et al., 1975

because of size, bark banding and injection have been investigated as methods of application as well as spraying. Foliar sprays tended to result in uniform retardation while bark banding mainly retarded the dominant shoots in a tree (Hield et al., 1978), and injection was species specific (Ufferman et al., 1979). In general, the growth regulator effectively controlled shoot elongation of tree species, although, at high concentrations, phytotoxicity caused visually unacceptable plants.

Growth promotion was observed in some plants (Table 4). This was not unexpected because the growth regulator promoted growth of Lycopersicon esculentum callus at very low concentrations, and had a synergistic effect with GA_3 (Bocion and de Silva, 1976).

Table 4. -- Species which showed a growth promotion response to dikegulac-sodium application

Species	Concentration	Promotion of stem growth (%)	Method of application
Acer saccharinum	8 ppm	44	injection[1]
Morus alba	100 %	39	bark banding[2]
Morus alba	50 %	29	bark banding[2]
Pinus radiata	50 %	29	bark banding[2]

[1]Ufferman et al., 1979

[2]Hield et al., 1978

Apical dominance

Increasing the number of shoots is important in commercial production of azalea (Rhododendron sp.) as it determines flower number. Removal of terminal buds by pinching releases apical dominance and increases the number of lateral shoots which can bear flowers. Chemical pinching agents have been sought to replace costly manual pinching.

Dikegulac-sodium increased the number of lateral shoots as well as or better than manual pinching (de Silva et al., 1976a; Sanderson, 1977; Sanderson and Martin Jr., 1977; Orson and Kofranek, 1978; Larson, 1978; Cohen, 1978a; Schnall and Day, 1979). The most effective range of concentrations was 4,000 to 6,000 ppm. When the growth regulator was used with manual pinching, more lateral shoots were produced than with either alone (de Silva et al., 1976a).

Despite the fact that more lateral shoots were formed by the growth regulator, more vegetative buds resulted than reproductive buds (de Silva et al., 1976a), and there was no significant increase in flower number (Sanderson and Martin Jr., 1977). The compact growth gave the growth regulator treated azaleas a better appearance than manually pinched azaleas (de Silva et al., 1976a).

The effectiveness of the growth regulator on the branching of azalea differed with various factors: cultivars (Larson, 1978); seasons (Orson and Kofranek, 1978); time of application in a day (Orson and Kofranek, 1978); and droplet size of the spray (de Silva et al., 1976a).

Pinching of euonymus (Euonymus fortunei) (Johnson and Lumis 1979) and increasing lateral shoots of pecan (Carya illinoensis) (Malstrom and McMeans, 1977 and Worley, 1980) by the growth regulator were also successful and the results were similar to those on azaleas.

Other physiological activity of dikegulac-sodium

A number of physiological effects of the growth regulator have been reported in addition to growth retardation and release of apical dominance. These include enhanced leaf abscission in Phaseolus vulgaris (Bocion et al., 1975) and Murraya paniculata (Criley, 1980), enhanced ripening in Lycopersicon esculentum (Bocion et al.,1975), enhanced

parthenocarpic fruit formation in Lycopersicon esculentum (Bocion et al., 1975) and Pyrus communis (Bocion and de Silva, 1976), inhibition of fruiting in Ilex crenata (de Silva et al., 1976b) and seed head formation in Poa pratensis (Nielsen and Wakefield, 1978), and induction of negative geotropism in Helianthus annuus (Purohit, 1980). Therefore the growth regulator probably interacted with hormones such as auxin, ethylene, and gibberellic acids.

Yellowing of expanding leaves at the time of application was the typical form of phytotoxicity for the growth regulator in most of the plants (Sachs et al., 1975; de Silva et al., 1976a; Hield et al., 1978; Jagschitz, 1975). It appeared 2 to 4 weeks after the application and the affected leaves usually regained normal green color in 6 to 8 weeks after the application.

In summary, spraying could be the best method of application for hedges because it is the most commonly used method, gave more uniform retardation and needs no special equipment. Other methods of application are not fully developed for hedge use. Dikegulac-sodium sprays could cause slow and even regrowth of mockorange hedge by inhibiting cell division and cell elongation at meristematic region and by suppressing shoot elongation and releasing apical dominance.

MATERIALS AND METHODS

Mature mockorange hedges were authorized for growth regulator sprays by the university at two locations on Oahu. Two growth regulators were chosen for a screening experiment from the results of previous research (Criley, 1980) in which 6 treatments were compared. Then, one was used for the rest of the experiments. The reason for limiting the growth regulator to one was to increase statistical significance from a limited number of plants.

The hedges were trimmed, sprayed with growth regulators, and shoot elongation was measured periodically. The experiments were set up to determine the optimal concentration for growth retardation without showing abnormal symptoms.

Plants and growth retardants

The Waimanalo hedges were located at the Waimanalo Experiment Station of University of Hawaii. There were two rows of the hedges consisting of 30 plants each planted approximately 60 centimeters apart in a northeast to southwest direction. They were planted in November 1969 and had previously received growth regulator sprays in June 1978. They were irrigated at the rate of 2.5 centimeters weekly by overhead sprinkler in addition to rainfall. The dimensions of the hedge were approximately 1.2 meter high, 1 meter wide, and 20 meters long.

The Kuykendall hedge was located between Kuykendall Hall and Campus Center of University of Hawaii. Oriented in a east to west direction, the plants were randomly and densely planted, and there were no visible boundaries of plants on the surface of the hedge. Most of the plants were planted within 20 centimeters apart. The age of the hedge was estimated to be more than 10 years old. The hedge was neither irrigated

nor fertilized, and trimmed 2 or 3 times a year. One part of the hedge was under the shade of a Mangifera indica (mango) tree. The dimensions of the hedge were approximately 1.2 meter high, 1.5 meter wide, and 40 meters long.

Sixty young seedlings were also acquired from a local grower in August 1979. They were transplanted into 15 centimeters pots in November 1979, fertilized, and placed under saran shade.

Dikegulac-sodium (Atrinal) and ammonium ethyl carbamoylphosphonate (Krenite) were acquired from Hoffman - La Roche Inc., Nutley, New Jersey and E. I. du Pont de Nemours & Co. (Inc.), Menlo Park, California respectively. They were stored in dark at room temperature.

Basic Procedure

All experiments in which mature hedges were used followed a basic procedure. This was developed through experiments making changes each time in order to show statistical differences and to reflect the nature of the hedge growth. Therefore, early experiments did not exactly follow the final procedure.

1. Trimming

The top surface of the hedge was trimmed horizontally and the sides were trimmed vertically. The level of the trimming was aimed at 1 to 2 centimeters above the previous trimming. This was to allow some error in the trimming and to insure that all parts of the hedge were not trimmed lower than the previous trimming. Electric shears were used.

2. Labelling

Treatments, replication numbers and identification numbers were written on labels and attached on the upper edges of the hedges. The label indicated the exact location of the spray.

3. Spraying

The hedges were sprayed with growth retardants in the morning when the weather was relatively stable. Areas of 30 centimeter square on the edge of the top surface of the hedges were covered with a device (Figure 1) to protect against possible drift and sprayed to run-off. The pressure was kept low to minimize drift (20 pounds per square inch or 1,406 grams per square centimeter). The nozzle number was 80067 and it was kept 10 centimeters above the hedge surface.

4. Tagging

Each plot was divided into 9 squares, 10 centimeters square each, and the 9 lateral shoots which were the closest to the centers were picked as subsamples. A guide was used for this purpose (Figure 2). Then they were tagged with modified plastic clips (Figure 3) so that the same shoots could be measured repeatedly.

5. Recording

Regrowth of the hedge was represented by the length of each new lateral shoot measured from its attachment to the old branch to the base of the apical bud. Actively growing shoots which originated lower than 3 centimeters from the trimming level were eliminated from sampling because they were usually dominant shoots which had not been trimmed. These generally elongated earlier than lateral buds on trimmed branches.

Two methods of sampling were used. In one the longest lateral shoot from each plot (one-longest-shoot) was chosen to represent the increase in height of the hedge. Three of the visibly longest shoots were measured and the longest of these were recorded biweekly. The other method used the 9 tagged lateral shoots (nine-subsampled-shoots) to represent the average length of the lateral shoots for the plot every 4 weeks.

Figure 1. A protective cover for spraying.

Figure 2. A guide for choosing subsample shoots.

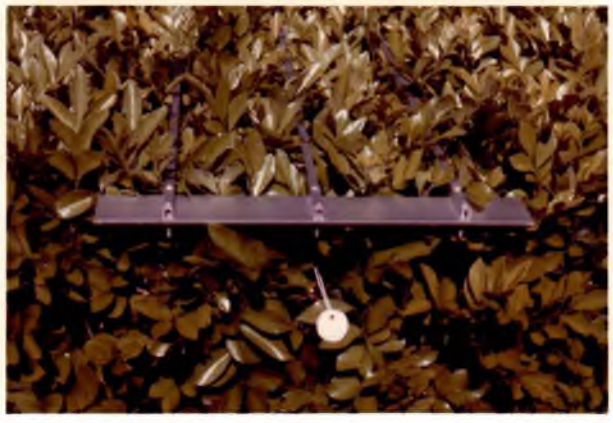


Figure 3. A plastic clip for tagging.

6. Analysis of data

An analysis of variance was performed on all data sets. Linear regression was used where response was linear. Mean separation was done where it was necessary. Frequency distributions and coefficients of variation were used to quantify apical dominance.

Preliminary Experiments

1. Screening

The Waimanalo hedges were trimmed on May 20, 1979 and sprayed with the growth regulators on June 18, 1979. The purposes of this experiment were to compare two growth regulators so that one could be chosen for additional study and to determine the maximum concentration for safe use in further experiments.

The treatments were control; 4,000, 6,000, 8,000, and 10,000 ppm active ingredient of dikegulac-sodium; and 1,000, 1,500, 2,000, and 2,500 ppm active ingredient of ammonium ethyl carbamoylphosphonate. The results of previous research (Criley, 1980) provided the second highest concentration of the growth regulators for this experiment.

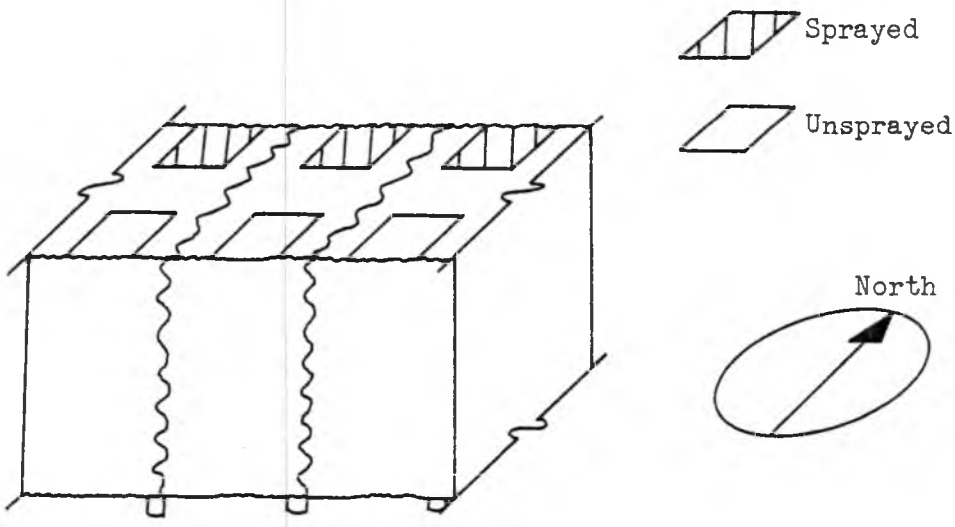


Figure 4. Plot design for the screening experiment.

The plots were paired oppositely on the north and south side of each plant (Figure 4). The treatments were randomized and sprayed on the north plots. The south plots were not sprayed and served as references. Each treatment was replicated 5 times. The length of nine-subsampled-shoots were measured. The effect of the growth regulators was to be expressed as percent growth of reference. The data were analyzed by analysis of variance using a completely randomized design.

2. Paired subplots to express the effectiveness of the spray

The Kuykendall hedge was trimmed on September 1, 1979 and sprayed with dikegulac-sodium (which was chosen by the screening experiment) on November 23 when the first new leaves were expanded. There were 5 treatments: 0; 2,000; 4,000; 6,000; and 8,000 ppm active ingredient (a.i.) of the growth regulator. The previous experiment gave the highest concentration which just started to cause unacceptable abnormal symptoms for a closely-viewed landscape (near landscape).

The purpose of this experiment was to determine if paired subplots could be used to express the effectiveness of the spray for further study because it might reduce the variability between individual plants. A previous study (Griset, 1970) failed to have a significant result because of inter-plant variability. In this experiment, each plot consisted of 2 subplots, an outside subplot for the spray and an inside subplot for reference. The treatments were replicated 5 times and randomized on both sides of the hedge (Figure 5). The effect of the growth regulator was to be expressed as percent growth of the neighboring reference. The lengths of nine-subsampled-shoots were measured 10 weeks after the treatment. The data were analyzed by analysis of variance using a completely randomized design.

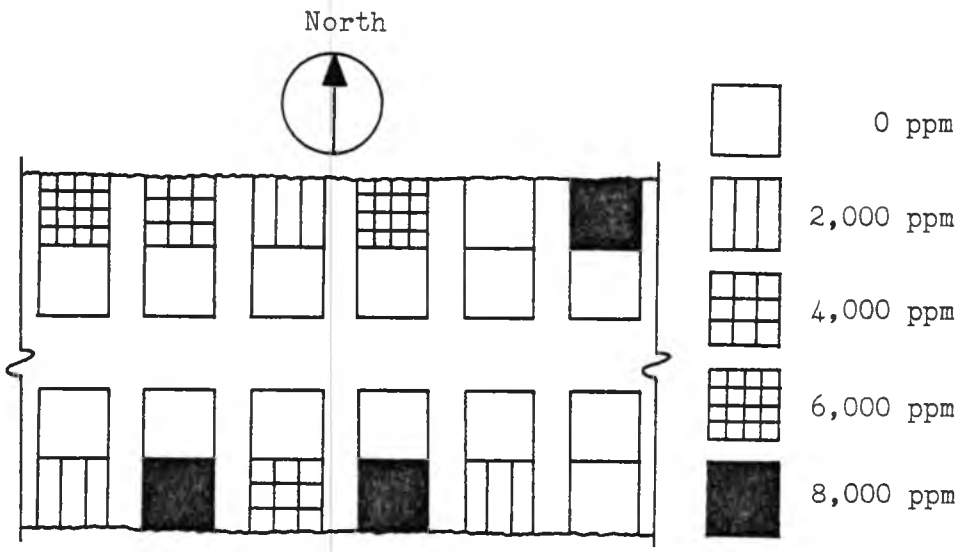


Figure 5. Plot design for paired subplots.

Experiment I: Effect of seasons on plant response to sprays of dikegulac-sodium

The Kuykendall hedge did not show regrowth after the trimming in September 1979 until November of that year and also after the trimming in August 1980 until December of that year. Therefore, 2 periods in a year were designated as seasons of growth for this study; April to August (spring application) and November to March (winter application). This division allowed 3 months of observation for each season. If there were differences in regrowth between these seasons, sprays of dikegulac-sodium might cause different effects on the plants. As an extreme example, the growth regulator spray was not needed in September and October probably because environmental stresses inhibited the regrowth in these months.

The hedge was trimmed on April 13, 1980 and sprayed with the growth regulator on May 6 for spring application, and it was trimmed on August 20, 1980 and sprayed on December 24 for winter application. Spraying was timed for when the first new leaves were expanded.

The plot design consisted of 3 replications, 2 sides (north and south) in each replication, and 5 treatments in each replication-side combination. The treatments were: 0; 2,000; 4,000; 6,000; and 8,000 ppm a.i. of the growth regulator, and they were randomized (Figure 6). The spray followed the basic procedure described in the previous section. The inside subplots used in the previous experiment were eliminated because the shoots in the inside subplots grew significantly longer than those in the outside subplots. The data were analyzed by analysis of variance for a split-block design.

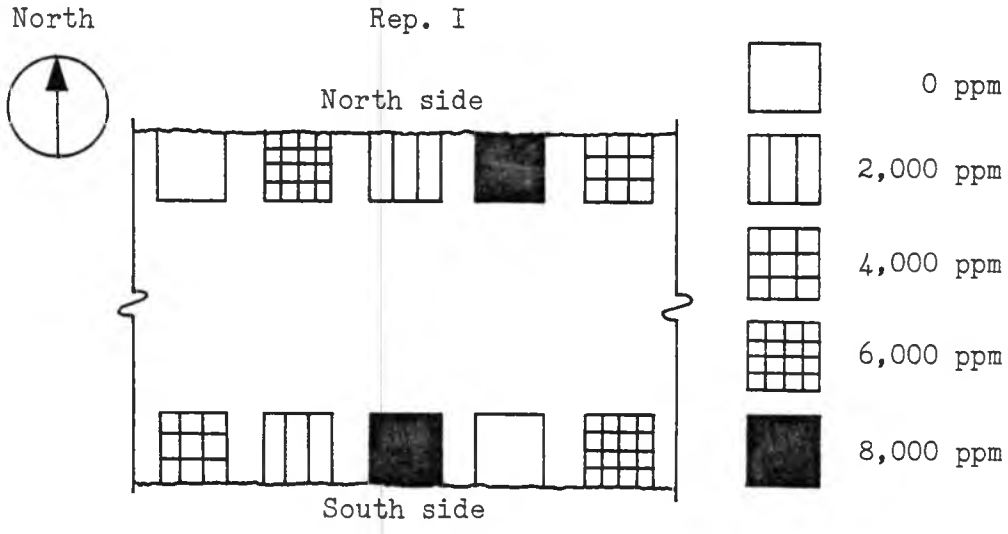


Figure 6. Plot design for experiment I.

Experiment II: Effect of stages of growth at the time of spray of dikegulac-sodium

When the Kuykendall hedge was trimmed in spring 1980, it was actively growing and the dormant lateral buds started to develop visibly approximately 10 days after the trimming. The purpose of this experiment was to find the most effective time to spray the growth regulator according to the bud development: at the trimming when the lateral buds were still dormant, at budbreak, and at the expansion of the first leaves.

The hedge was trimmed on April 13, 1980, and a part of the hedge was sprayed with the growth regulator at 3 dates: April 15, at the trimming; April 26, at budbreak; May 6, at the expansion of the first leaves.

The plot design consisted of 3 replications, 2 sides (north and south) in a replication, 3 spray dates randomized in each side of a replication, and 5 treatments randomized in each spray date (Figure 7). The treatments were: 0; 2,000; 4,000; 6,000; and 8,000 ppm a.i. of the growth regulator. The basic procedure was followed for the sprays. The data were analyzed by analysis of variance using a split-block design.

Experiment III: Effect of shade on plant response to sprays of dikegulac-sodium

A part of the Kuykendall hedge which was under the shade of a mango tree usually grew slower than other part which was under full sun. This shade could cause a difference in the effectiveness of the growth regulator.

The shaded part of the hedge was sprayed on May 11 with the same concentrations as used for experiments I and II. The May 6 spraying of the experiment on stage of growth was used for the full sun comparison.

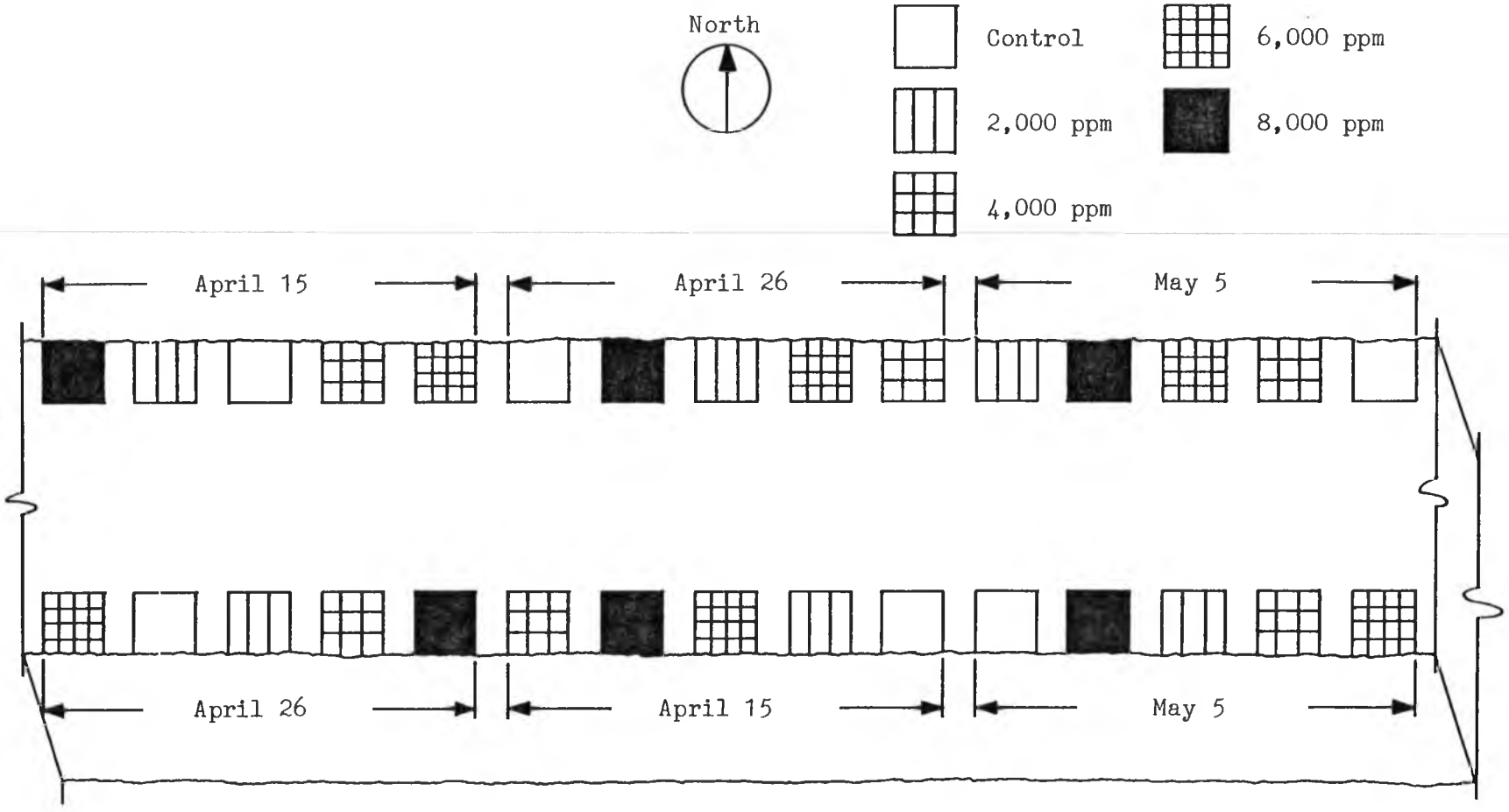


Figure 7

Plot design for Experiment II

The plot design consisted of 3 replications, 2 siedes in each replications (north and south), and 5 concentrations randomized in each side of a replication. The basic procedure was followed for the spray. The data were analyzed by analysis of variance using a completely randomized design.

Experiment IV: Effect of vigor on plant response to dikegulac-sodium

At the Waimanalo site, one hedge usually grew faster than the other and end plants of the hedges were much more vigorous than inside plants. These variations could have come from internal and external factors: such as genetic make-up; availability of water; nutrient, and solar radiation; property of underlying soil; established root system; and previous sprays. In the field most of those factors are difficult to control. If the growth rate was the result of the sum of those factors and had an interaction with dikegulac-sodium sprays then an economical use of the growth regulator could be achieved, i.e. adjusting the concentration according to vigor of plants.

The Waimanalo hedges were trimmed on November 1, 1980, and one-longest-shoots from the southwest plots were measured on January 13, 1981 as references. The hedge was trimmed again on January 14, sprayed with 0 and 4,000 ppm a.i. of the growth regulator on January 29, and measured again on March 17. The regrowths of the second period were expressed as percentages of the regrowth of the first. Plotting the percentage (arcsine transformed) and the reference gave 2 regression lines, one for sprayed and the other for control. The variances, the slopes, and the means were compared using the analysis of variance for regression (Snedecor and Corchran, 1967).

Experiment V: Effect of washing leaves after application of dikegulac-sodium in seedlings

In Hawaii, unexpected rain is not unusual. One has to decide if he should spray again or not when it rains within a few hours after spraying. The Technical Data Sheet for dikegulac-sodium (Anonymous, 1979) stated that 6 hours was generally sufficient for the absorption. Since absorption can differ among plants and environments, it would be beneficial if the time necessary for sufficient absorption to effect a plant response could be determined for the plant in Hawaii.

The seedlings were topped on November 20, 1980 to a height of approximately 50 centimeters. The leaves on the stem were removed except for the top 5 leaves. All lateral shoots were removed. The seedlings were treated with the chemical on November 23 by dipping the most distal leaves into 4,000 ppm a.i. solution of the growth regulator for 3 seconds. Treated leaves were washed with running water for 30 seconds 0.5, 1, 2, 4, or 8 hours after dipping. One treatment was not dipped for control (Figure 8). Each treatment was replicated 8 times. The elongation of lateral shoots subtended by leaves and the number of internodes were recorded twice a week for 6 weeks. The result was analyzed by analysis of variance using a completely randomized design.

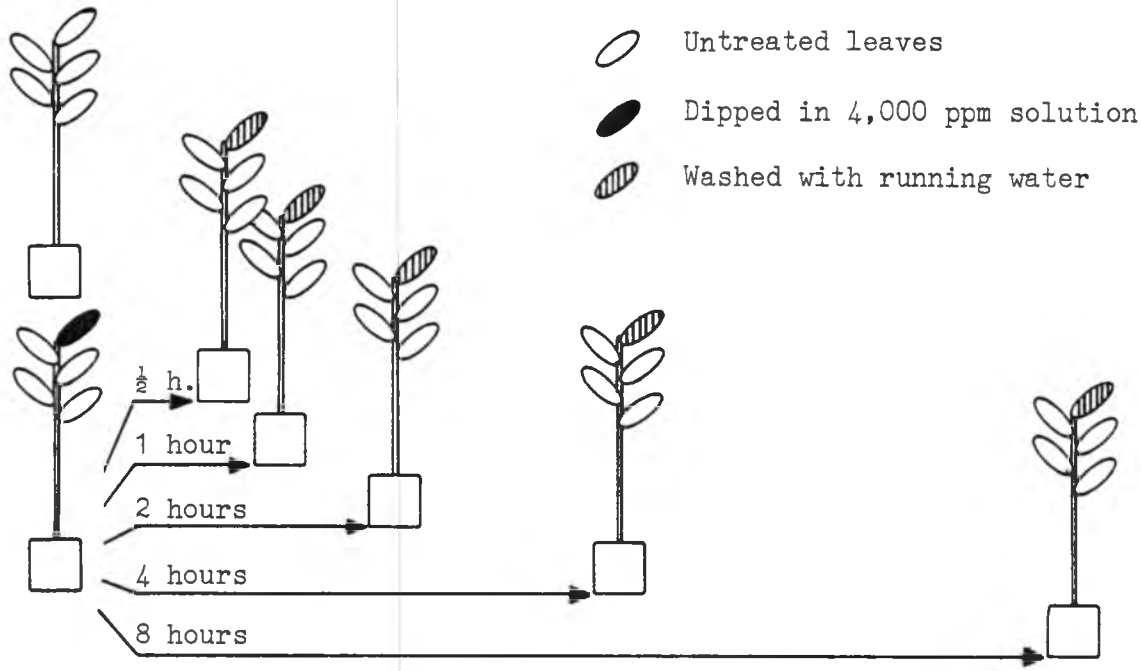


Figure 8. Treatment procedure for experiment V.

RESULTS AND DISCUSSION

The basic unit of measurement for the experiments in this thesis was the length of lateral shoots in centimeters, and the data were subjected to the analysis of variance procedure. Since a normal distribution of the data was essential for this procedure, the normality of lateral shoot distribution was tested by Kolmogorov-Smirnov D-statistic (Stephens, 1974) for both the nine-subsampled-shoots and the one-longest-shoots from each plot.

A representative of frequency distribution of the nine-subsampled-shoots, consisting of 810 observations, were taken on June 24, 1980 from Experiment II. The distribution was skewed to the left (skewness = 1.38), leptokurtotic (kurtosis = 2.73), and significantly deviated from normal distribution at less than 1 percent level. This distribution had characteristics of a log normal distribution. Since logarithmic transformations are frequently needed in the analysis of variables related to the growth of organisms (Sokal and Rohlf, 1969), the original data were transformed to common logarithms. The transformed frequency distribution of lateral shoots was not as skewed (skewness = -0.01) as the original distribution and was slightly platykurtotic (kurtosis = -0.43). The deviation from a normal distribution was not significant as 1 percent level but at 4.4 percent level. Even though the goodness of fit to a normal distribution was not completely satisfactory, the transformation improved normality to the point that an analysis of variance would be valid enough on the nine-subsampled-shoots.

A similar result was learned from the frequency distribution of the one-longest-shoots in spite of the report of Brown et al. (1977) which stated that the mean lengths of the longest sprout of American sycamores

were approximately normally distributed.

These tests for normality provided the bases for valid analysis of variances. Therefore all observations of the lateral shoot growth of mockorange hedges were subjected to logarithmic transformation. The data sets which had a zero value (X = 0) were transformed as log (X+1) and others were transformed as log X.

Preliminary Experiments

1. Screening

Uniformity of growth of the hedges in Waimanalo was checked by analysis of variance using plants which were not treated on both sides. If there was no significant difference between two sides of the hedges, the growth retardation on the treated side could be expressed as a percentage of the untreated side and the variance between plants could be reduced. But the result indicated that the regrowth was not uniform (Appendix Table 1). The differences between hedges, between plants within hedge, and between sides within plants were all significant at 13 weeks after the trimming. Therefore the initial idea of expressing the growth retardation as a percentage of control was not used.

The effectiveness of two growth regulators were compared by analysis of variance using only the treated side of one of the two hedges (Appendix Table 2). The results indicated that the growth regulator sprays did not retard the regrowth significantly at 8 and 14 weeks after the applicationexcept for ammonium ethyl carbamoylphosphonate at 8 weeks. Therefore the choice of a growth regulator was not made by this analysis.

There was a large difference in abnormal symptoms caused by the growth regulators. Dikegulac-sodium caused severe yellow and necrotic spots on developing leaves with 10,000 ppm, while lower concentrations

did not cause unacceptable abnormal symptoms. On the other hand, all concentrations of ammonium ethyl carbamoylphosphonate caused leaflet drop and marginal chlorosis on mature leaves and the latter persisted for 14 weeks.

Even though the growth data did not show significant growth retardation, the visual effect was that both growth regulators retarded the regrowth of the hedges. Since dikegulac-sodium was less harmful to the appearance of the hedges for approximately the same growth retardation as ammonium ethyl carbamoylphosphonate, it was selected for further study, and 8,000 ppm of the growth regulator was chosen for the highest concentration.

2. Paired subplots to express the effectiveness of the spray

Paired subplots were laid across the direction of the Kuykendall hedge to reduce the variance caused by plants. The uniformity of growth was checked again using untreated subplots. The results showed that the regrowth between the positions of subplot, inside and outside, were significantly different (Appendix Table 3). The inside subplots showed faster regrowth than the outside subplots. Therefore it was decided that instead of using reference subplots to express the effectiveness of a growth regulator in reducing the variance caused by plants, replications of randomized complete block design (split-block design for hedges) would be used to reduce the variance.

Using outside subplots, the response of lateral shoots to dikegulac-sodium concentrations is shown in Figure 9. The regrowth was promoted by the growth regulator, and linear and cubic components of the concentrations were significant (Appendix Table 4). The south side of the hedge was significantly taller than the north side while 2,000 to 6,000

ppm of the growth regulator narrowed the difference. Even though the measurement indicated growth promotion, the visual effect was retardation according to the concentration. Therefore one more method of sampling, one-longest-shoot from each plot, was added to the nine-subsampled-shoots method. The basis of this measurement was that if a plot was considered as an experimental unit measuring the longest shoot would be a valid sampling method. It also appeared that measurement could represent the visual regrowth of the hedge.

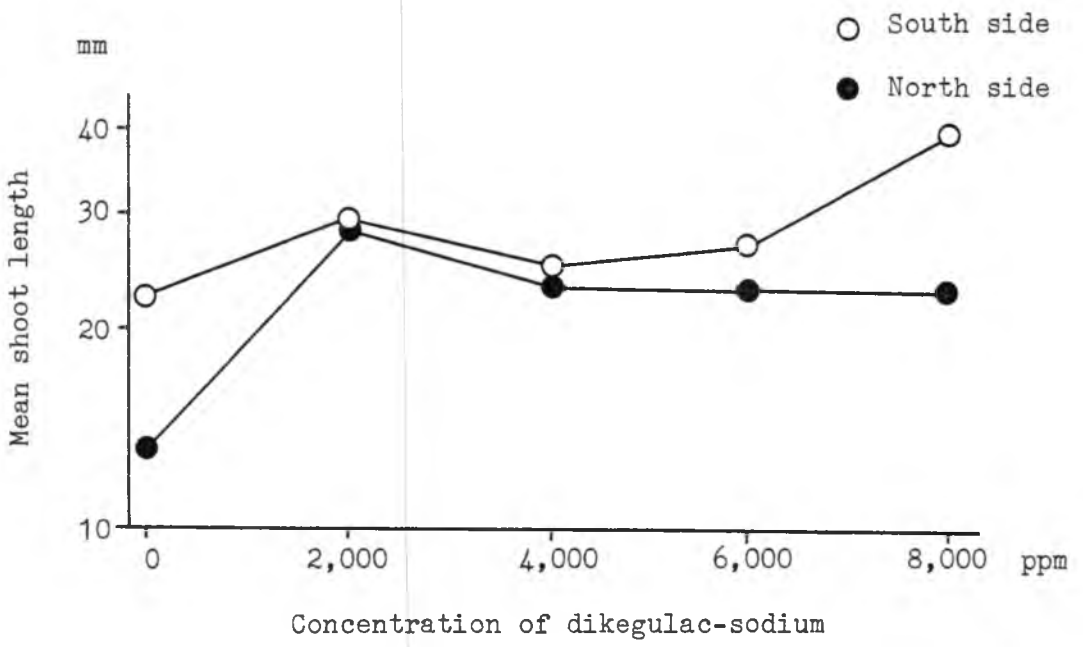


Figure 9. Effect of dikegulac-sodium on subsampled lateral shoots at 10 weeks after the sprays.

The results of the preliminary experiments produced the following conclusions:

1. Dikegulac-sodium was selected for further study, and 8,000 ppm of the growth regulator was chosen for the highest concentration.

2. Split-block should be used for plot design without reference plots.
3. Two methods of sampling should be used, one-longest-shoots and nine-subsampled-shoots method.

Experiment I: Effect of seasons on plant response to sprays of dikegulac-sodium

Growth of the one-longest-shoots from controls was plotted against time for two seasons in Figure 10. Week 0 of the graph was when the first leaves expanded for both seasons. The hedge showed the maximum growth rate (when the slopes were the steepest) approximately 3 weeks earlier in spring than in winter. Regrowth slowed after 8 weeks in spring, but not in winter. The hedge was actively growing at trimming in spring but was inactive in winter. Therefore physiological conditions of the hedge such as availability of carbohydrate, levels of hormones, and morphology of the lateral buds could have been different with the seasons.

The effect of the growth regulator was examined for both methods of sampling as represented by measurements 8 weeks after treatment when the lengths for control were approximately equal for the two seasons.

The means of the one-longest-shoots are plotted on Figure 11 and the analysis of variance is shown in Appendix Table 5. The concentrations were significantly different at the 1% level in spring but were not significant in the winter. Means for 0 ppm were approximately identical for the two seasons. Therefore the growth regulator was effective in suppressing the growth of the longest shoot in spring but not effective in winter. The north side grew faster than south side and the difference decreased as concentrations increased. Growth enhancement was seen at 2,000 ppm of the growth regulator in winter. Analysis of variance was

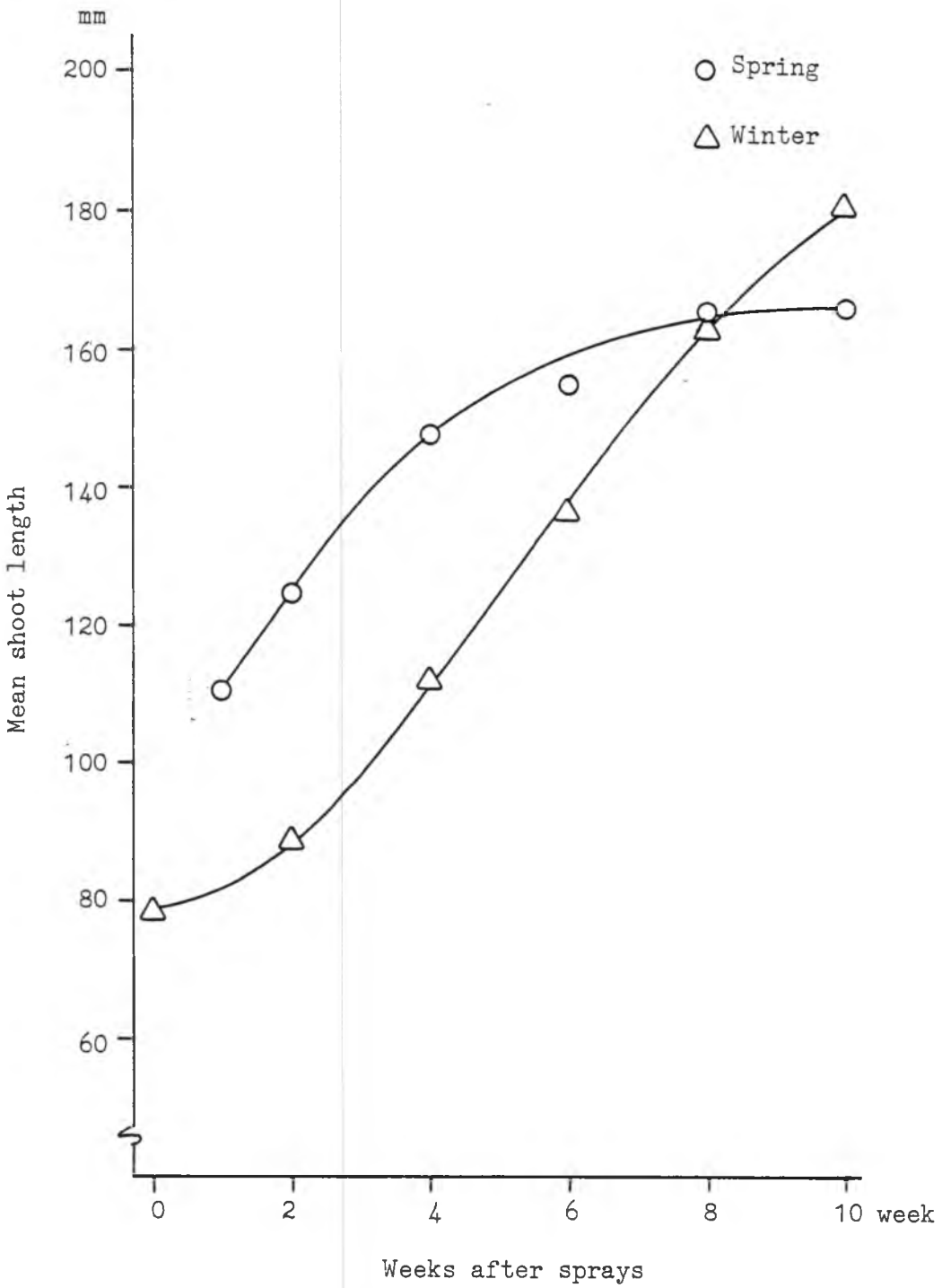


Figure 10. Growth of the longest shoots of control plots for two seasons.

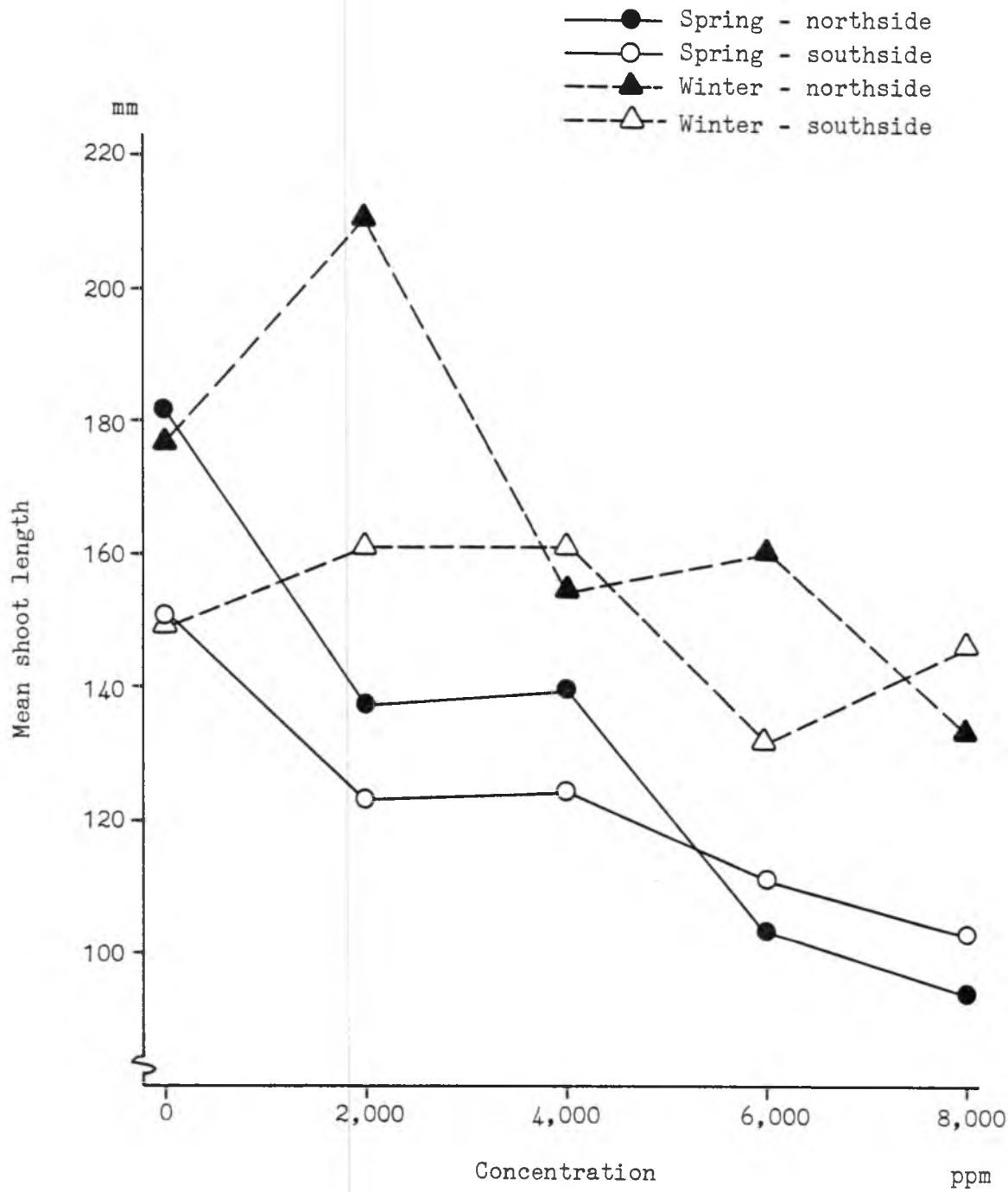


Figure 11. Response of the longest shoots to concentration of dikegulac-sodium at 8 weeks after the sprays.

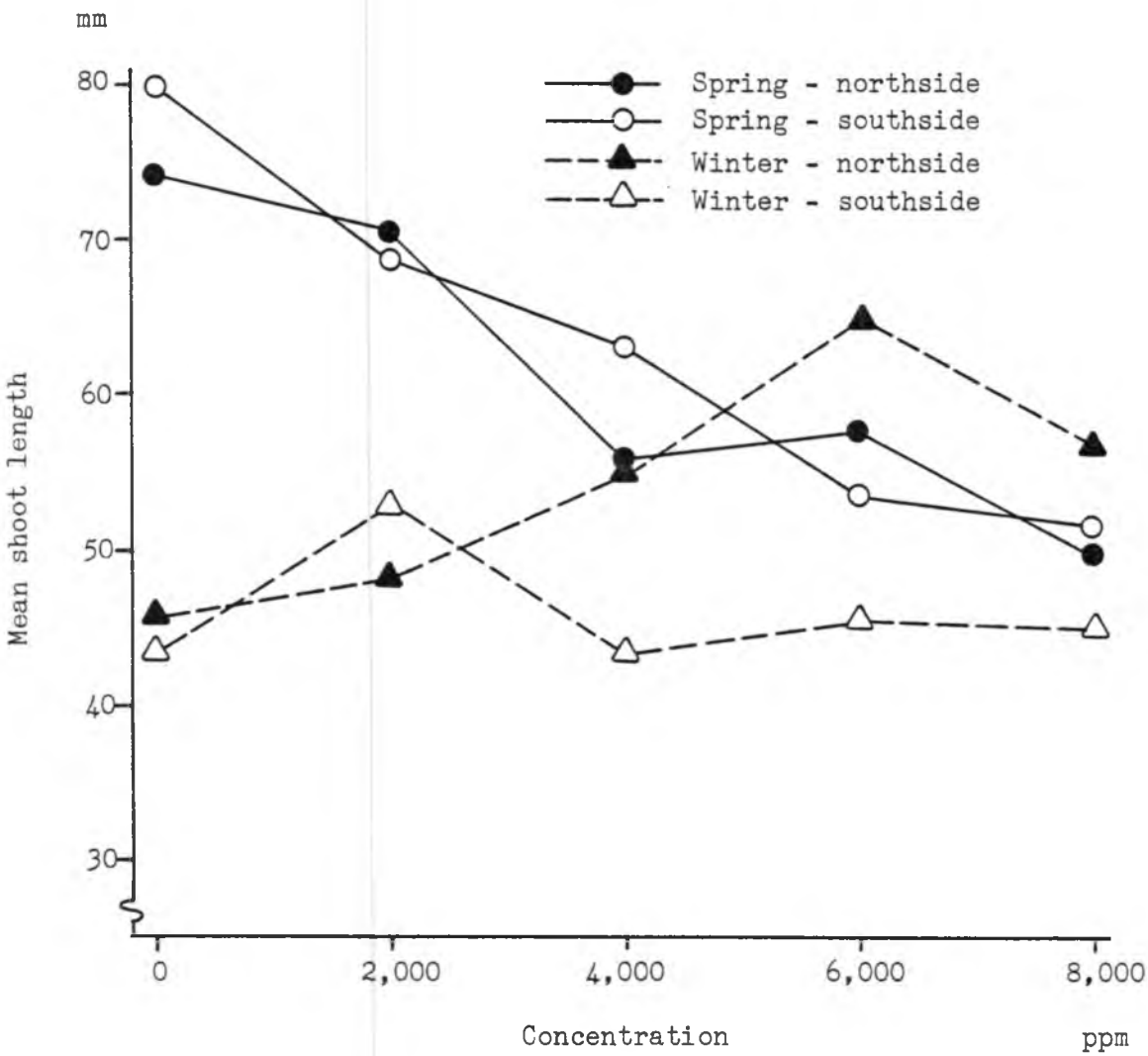


Figure 12. Response of subsampled shoots to concentration of dikegulac-sodium 8 weeks after the sprays.

done every other week, and the characteristics were the same as for 8 weeks as shown in Appendix Table 5. The significant result for concentration in spring was consistent from 1 week to 10 weeks.

The means of the nine-subsampled-shoots are plotted in Figure 12 and the analysis of variance is shown in Appendix Table 6. The plots with 0 ppm treatment had a large difference between two seasons. The growth of shoots in winter was 58% of shoots in spring. But there were no difference between sides over both seasons. The growth regulator decreased the growth linearly on both sides in spring with 1% level significance but not in winter. Sides of the hedge were significantly different in winter and the north side showed growth promotion with high concentrations.

If the strength of apical dominance between lateral shoots is represented by a large coefficient of variation, there is a difference between the two seasons. Figure 13 shows frequency distributions of nine-subsampled-shoots and their coefficients of variation by seasons and concentrations. Apical dominance of the hedge was stronger in winter (c.v. = 74.5%) than in spring (c.v. = 55.5%) and weakened as concentration of the growth regulator increased. The frequency of long shoots decreased in both seasons as concentration increased, while the frequency of short shoots increased in spring and decreased in winter. Therefore the growth regulator reduced the elongation of dominant lateral shoots in both seasons and suppressed lateral shoots in spring, but it permitted the elongation of suppressed lateral shoots in winter.

McIntyre (1971) reported that bud growth of isolated rhizomes of Agropyron repens was positively correlated to the availability of stored nitrogen supply and the translocation of nitrogen occurred acropetally.

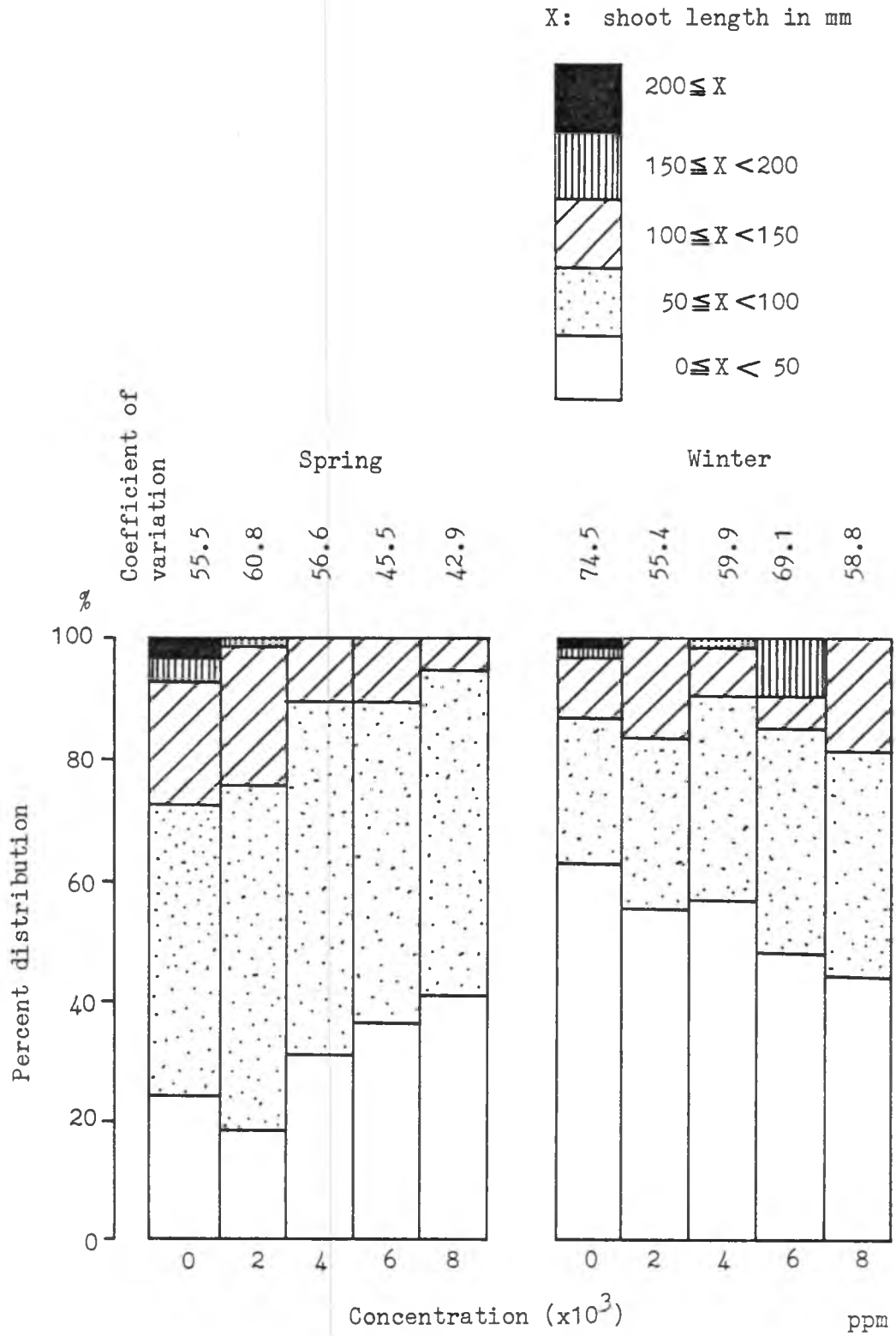


Figure 13. Comparison of seasons on plant response to dikegulac-sodium 8 weeks after the spray.

If the same mechanism occurred in trimmed branches of the mockorange hedge the difference in the response to the growth regulator could be explained as follows: In winter, metabolites were relatively scarce, dominant lateral shoots consumed them and suppressed lateral shoots were starved. While the growth regulator selectively inhibited the cell division of actively growing meristems in dominant lateral shoots and their elongation, suppressed lateral shoots were allowed to grow receiving diverted metabolites. In spring, there were enough metabolites produced by leaves so that many suppressed lateral shoots had activity within their meristems. Therefore the growth regulator would be translocated non-selectively to all active meristems and suppress shoot growth. This explanation might well explain the plant response to the growth regulator as represented by Figures 11 and 12.

Conclusions drawn from experiment I were:

1. Apical dominance was stronger in winter than in spring.
2. The growth regulator was effective in suppressing growth of the hedge in spring but not in winter.
3. The growth regulator selectively suppressed the growth of actively growing lateral shoots but was not effective on inactive lateral shoots.

Experiment II: Effect of stages of growth the time of spray of dikegulac-sodium

Average growth of the shoots sprayed with 0 to 8,000 ppm dikegulac-sodium in spring, was plotted against time in Figure 14 to show the difference between three stages of growth at the time of spray. Each plot represented a mean of 30 longest shoots. Growth of the longest shoots sprayed with each concentration is also plotted against time in Appendix Figure 1A to 1C by each stage of growth at the time of spray. The difference between stages of growth at the time of spray was not significant at 10 weeks after trimming (Appendix Table 7).

Growth of the hedge generally showed 2 flushes in 18 weeks from the trimming, in which first flush of growth lasted approximately 6 weeks and the second lasted at least 12 weeks (Figure 14). At the end of each flush of growth, newly formed stems were lignified. Sprays of the growth regulator did not cause a shift in the flush pattern except for a slight elongation of first flush for sprays applied at the expansion of the first leaf.

The growth pattern in flushes was reported by Greathouse et al. (1971). They showed that growth of Theobroma cacao shoot was rhythmic by alternating flushing and dormancy periods. In the greenhouse the plants grew in unsynchronous 27 day cycle, and in the field the cycle was approximately 30 days longer extending only the dormancy period. They suggested that the plant had an endogenous rhythm which became apparent when proper environmental conditions existed. They also found that leaves and leaf primordia for succeeding growth were already present in the dormant bud, and they were produced during the flushing period.

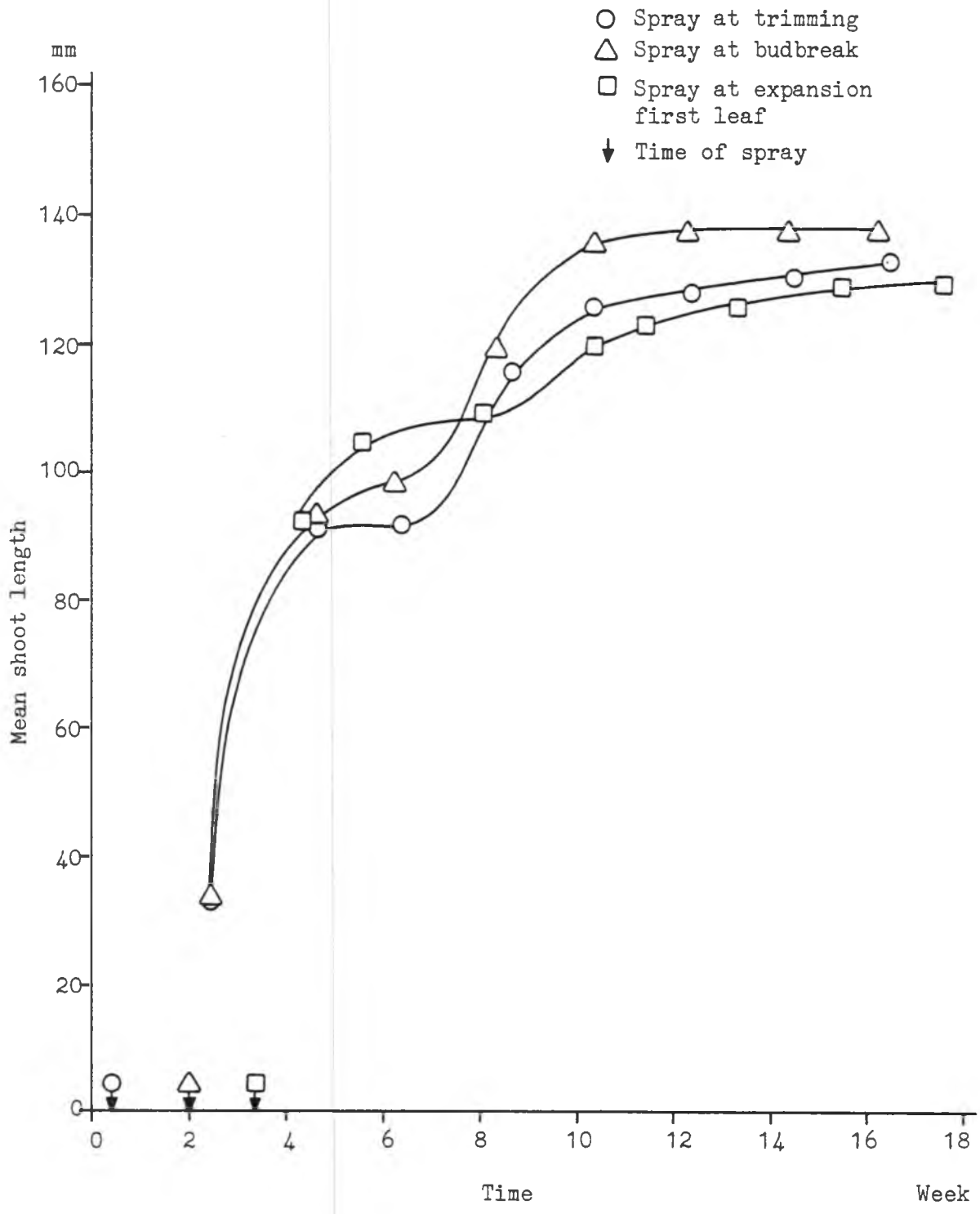


Figure 14. Average of the longest shoots sprayed with 0 to 8,000 ppm dikegulac-sodium at three stages of growth.

The mechanism of growth inhibition of the lateral shoots could be explained by growth rhythm of mockorange and selective inhibition of cell division and cell elongation by dikegulac-sodium. When the growth regulator was sprayed, internodes and leaves for the flush were already formed in the buds, and apical meristems were actively dividing for the next flush. Therefore the growth regulator retarded shoot elongation in the first flush mainly by inhibiting cell elongation but retarded shoot elongation in the second flush by inhibiting cell division at apices (Zilkah et al., 1977).

Table 5 shows mean growth for each flush as calculated from Figure 14. The earliest treatment (spray at the trimming) caused the most reduction of growth in the first flush since the growth regulator was effective from the start of the growth by inhibiting cell elongation. But the latest treatment (spray at the expansion of first leaf) caused the most reduction of growth in the second flush probably because the apical meristems were dividing most actively at the time of spray. Growth retardation by this combination (inhibition of second flush by spray of the growth regulator at the expansion of first leaf) was the most effective probably because a smaller amount of the growth regulator was necessary to inhibit cell division than cell elongation (Argee et al., 1977).

Table 5. -- Comparison of mean growth of lateral shoots over two flushes following treatment with dikegulac-sodium at three stages of growth.

Stage of growth at spray	Mean growth in mm (% of control)			
	First flush		Second flush	
Trimming	91	(76%)	42	(83%)
Budbreak	97	(81%)	41	(80%)
Expansion of first leaf	108	(90%)	20	(41%)
Control	120	(100%)	51	(100%)

The plant response to concentrations was roughly linear for both methods of sampling (Figure 15), but no difference was found between the stages of growth at the time of spray. This linear response to concentration showed early (2 to 4 weeks) and was consistent to the end of the experiment (Appendix Table 8). Therefore the effectiveness of the growth regulator in suppressing growth of the hedge could be estimated by the concentration, and this is discussed in the latter section in this paper.

The effect of sides of the hedge and the interaction between sides and concentrations were not significantly different due to the concentration-oriented split-block design for this experiment. The interaction between sides and stages was significantly different at 10% level. Regression lines for each side and stages of growth at the time of spray are displayed in Appendix Figure 2. They were well fitted to linear regressions except the south side sprayed at bud break. Generally, one side of the hedge had steeper slopes than the other, and the differences of length between sides decreased as concentration of the growth regulator became higher.

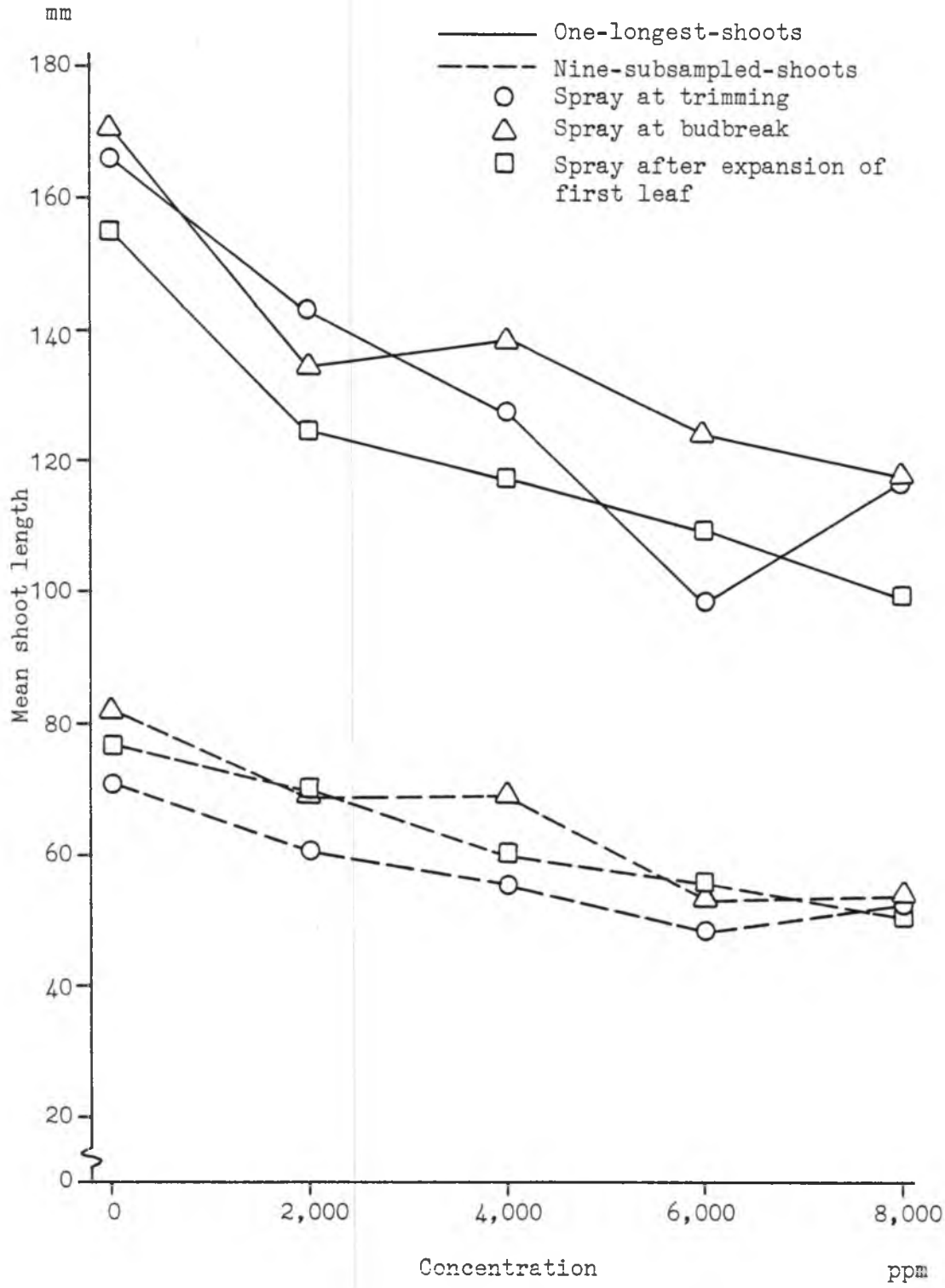


Figure 15. Response of lateral shoots to concentration of dikegulac-sodium at 10 weeks after spraying.

Phillips (1975) discussed establishment of apical dominance after decapitation of the dominant shoot. The size of dormant buds usually increased within a day after decapitation. In this experiment the first sprays were applied 3 days after trimming. Therefore reestablishment of apical dominance could have occurred by the time of spray. If the spray was applied immediately after trimming, it could reduce apical dominance more effectively.

Conclusions drawn from experiment II were:

1. The hedge showed 2 flushes of growth in 18 weeks after trimming.
2. Dikegulac-sodium could have different mechanism of growth inhibition for 2 flushes, inhibiting cell division and cell elongation at different site of apical meristem.
3. Growth retardation was observed in early stage of the first flush and it was persistent to the end of the second flush.
4. Response of the plant to concentration of dikegulac-sodium was linear to 8,000 ppm with negative slope.

Experiment III: Effect of shade on plant response to spray of dikegulac-sodium

Means for full-sun and shade treatment are shown in Figure 16 by concentrations and two methods of sampling, while the analysis of variance for growth of shoots is shown in Appendix Table 9. The means for both methods of sampling showed similar curves when plotted against concentration. There was a significant difference between full-sun and shade treatments at the 1% level. Sides and concentrations were also significant at the 5% and 1% level respectively.

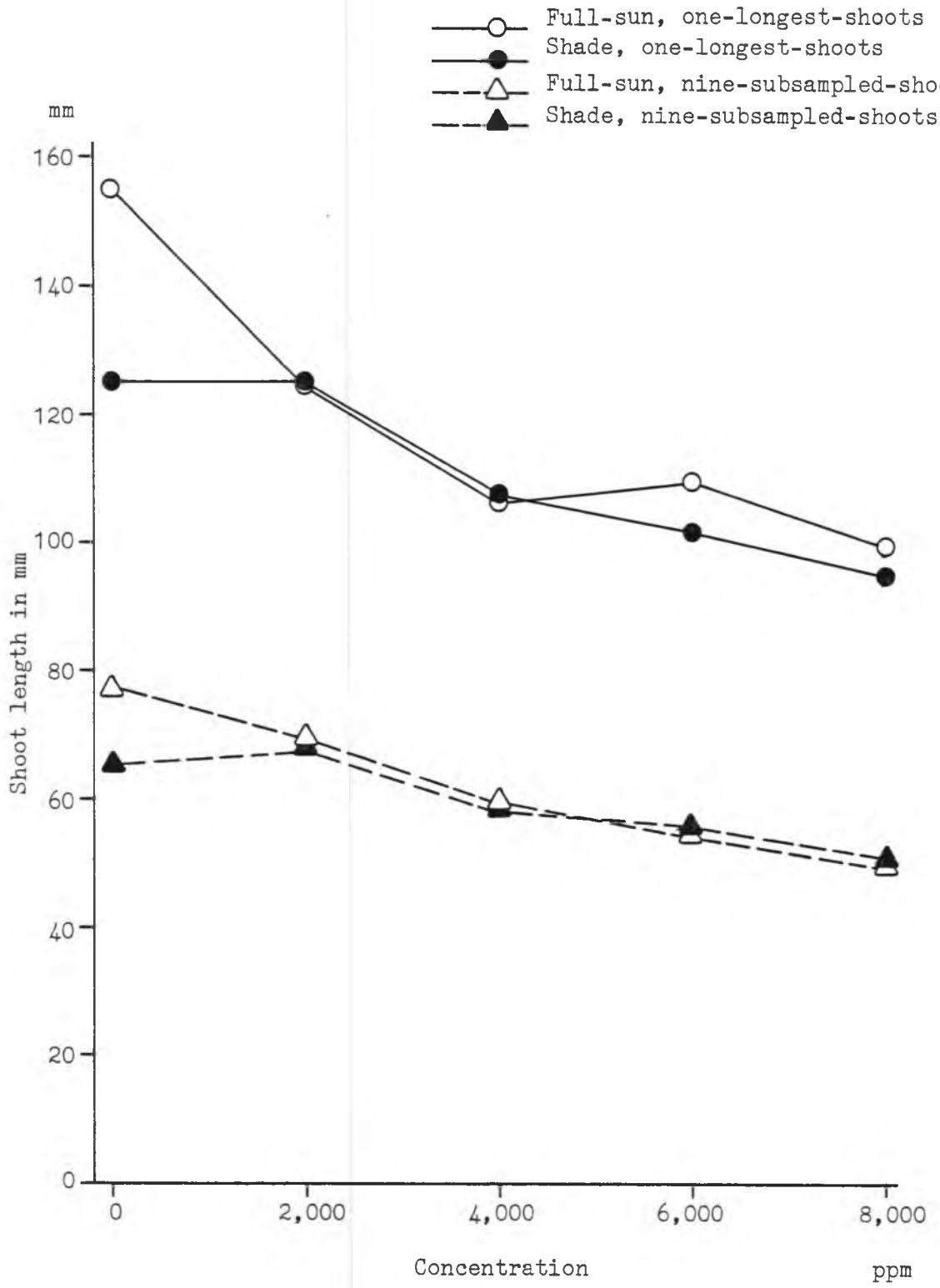


Figure 16. Response of lateral shoots sprayed with dikegulac-sodium to shade at 10 weeks after the sprays.

The strength of apical dominance was probably not altered by shade because slopes for two treatments on nine-subsampled-shoots were almost identical between 2,000 to 8,000 ppm of the growth regulator which would result in similar values of coefficient of variation. If the apical dominance was altered, the slope would be different since the growth regulator weakens apical dominance. The cause of the significant difference between treatments was found only in control plots. With 0 ppm of the growth regulator full-sun plots and shade plots grew at different rates, but with 2,000 ppm they grew at the same rate which was approximately the same level of shade plots with 0 ppm. Therefore the growth suppression caused by the shade was equivalent to a spray of the growth regulator at 2,000 ppm.

Conclusions drawn from experiment III were:

1. Shade reduced the growth of all lateral shoots that had not been treated with dikegulac-sodium.
2. Shade did not change the strength of apical dominance.
3. The amount of suppression caused by shade was equal to that caused by spray of 2,000 ppm of dikegulac-sodium and their effects were not additive.

Experiment IV: Effect of vigor on plant response to dikegulac-sodium

Plots of the data and two regression lines are shown in Figure 17 and comparison of the regression lines is shown in Appendix Table 10. The residual mean for the two regression lines and difference between slopes were not significant. But the difference between the means was significant at the 1% level.

The analysis of variance indicated two treatments had the same variability, that analysis could continue (F test for the treatments was

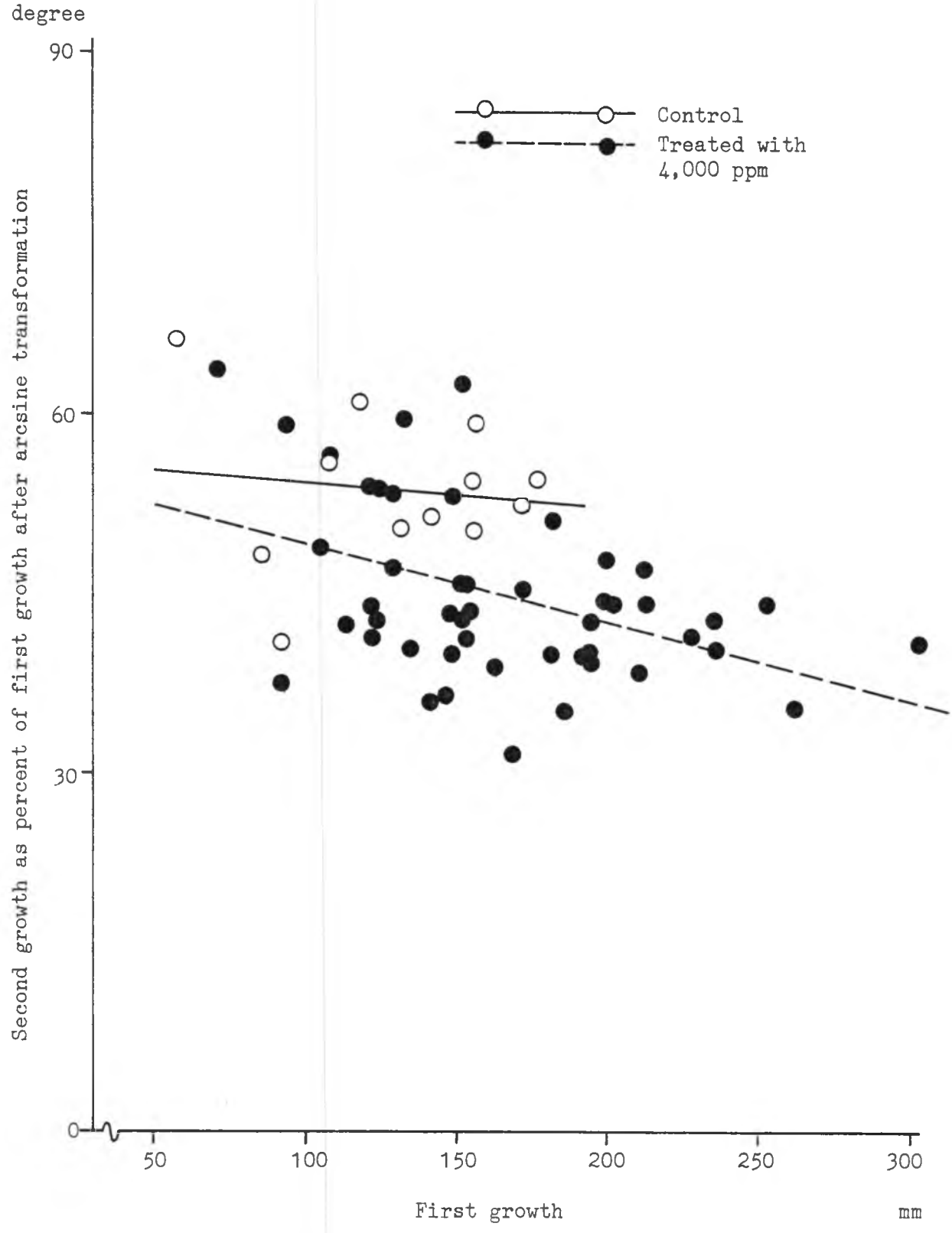


Figure 17. Response of lateral shoots sprayed with 4,000 ppm dikegulac-sodium at 48 days after the treatment.

not significant), that the treatments did not interact with vigor of the plant (difference between the slopes was not significant), and that the treatment reduced stem elongation (difference between the means was significant).

The slightly negative slope of control plots, if it was true, could be caused by different growth rates against time in the two periods of regrowth. The more negative slope for the treatments compared with the controls could be an indication that the growth regulator more effectively suppressed vigorous shoots than less vigorous shoots. However, variances within treatments were too big for the test to be significant. The range for the controls should have been as wide as the treatments.

Conclusions drawn from experiment IV were:

1. Spray of dikegulac-sodium at 4,000 ppm suppressed lateral shoot growth of the plant in all ranges of vigor in winter.
2. The effectiveness of the treatment was not changed by the vigor of the shoot at the time of application.

Experiment V: Effect of washing leaves after application of dikegulac-sodium

Mean shoot lengths at 5 positions for each treatment are shown in Figure 18. Time of exposure to dikegulac-sodium is on horizontal axis, position of lateral shoots is on vertical axis, and mean shoot lengths are on the axis perpendicular to the paper. The analysis of variance is shown in Appendix Table 11. Position of lateral shoots was significant at the 1% level but total growth was not significant with time of exposure. Analysis of variances by position of lateral shoots was significant only for the first and fifth shoots, and the results of Duncan's multiple range test at the 5% level are shown in Figure 18.

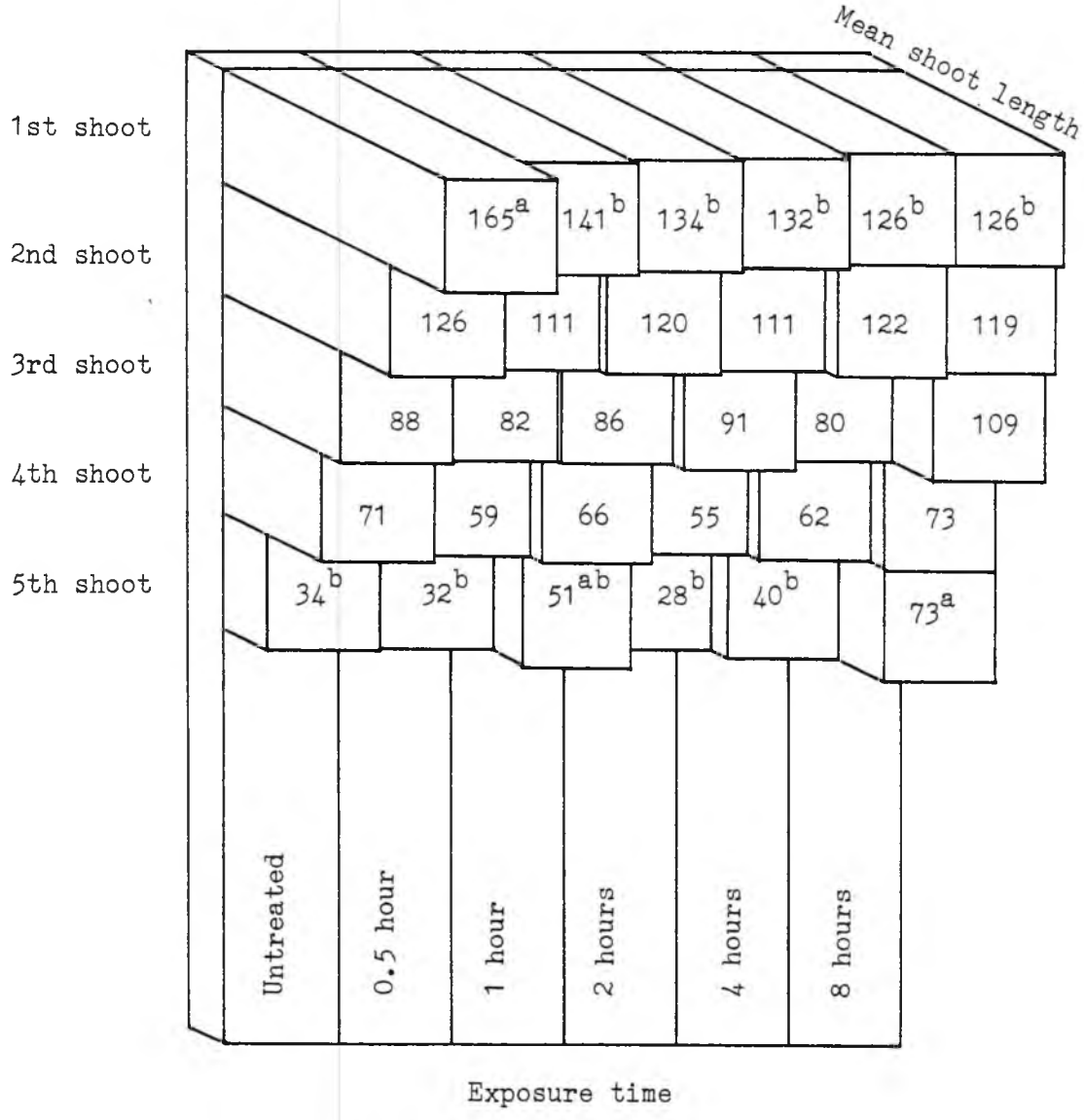


Figure 18. Effect of exposure time to dikegulac-sodium on shoot development at 5 distal nodes.

All treatments were different from untreated for the first shoot position, but there were no differences among other treatments. For the fifth shoot position, the 8 hours treatment was different from all others except the 1 hour treatment. The analysis of variance for number of internodes at the first shoot position is shown in Appendix Table 12. There was no significant difference among treatments, and the mean was 5.3 ± 0.9 (standard error).

Untreated plants in Figure 18 showed a typical pattern of apical dominance for the first shoot to fifth shoots, and the growth regulator applied to the distal leaf decreased the strength of apical dominance. One-half hour of exposure to the growth regulator was enough to reduce the growth of the dominant first shoot significantly. Second shoots did not grow taller than the first shoots in any treatments. Since there was no difference in total growth between treatments, metabolites which were not consumed by the first shoot were probably diverted to lower shoots according to the apical dominance in treated plants. In the hedge, reduction of apical dominance would increase the quality of hedge by increasing the number of active branches and reduce the rate of growth through competition among branches. The growth regulator did not suppress the growth of lateral shoots by decreasing the number of internodes but by decreasing internode length, because total length of the shoot was inhibited while the number of internodes was not changed.

Conclusions drawn from experiment V were:

1. One-half hour of exposure to dikegulac-sodium was enough to reduce the growth of first shoot significantly in saran house.
2. The growth regulator caused the reduction of internode length but did not change the number of internodes.

Abnormal symptoms caused by dikegulac-sodium

Mockorange showed several abnormal symptoms caused by the spray of dikegulac-sodium. Since abnormal symptoms were shown in all experiments, they are discussed together in this section instead of separately.

There were 7 major abnormal symptoms shown on the plants sprayed with the growth regulator.

1. Necrotic spots on young leaves (Figure 19A): Necrotic spots usually showed at the leaf margin on young leaves 2 weeks after the spray. The symptom was persistent but became inconspicuous after second flush of young leaves. Spraying the growth regulator at earlier stage of growth eliminated the symptom. The symptom could be due to a high concentration of growth regulator localized at the leaf margins when droplets of the solution on the leaflets evaporated or acropetal movement and accumulation at the leaf margins.
2. Leaflet drop of young leaves (Figure 19B): Expanding and young mature leaves were very susceptible to leaflet drop caused by the spray of the growth regulator. The symptom was observed 2 weeks after the spray. Leaflets of the plant had a distinctive abscission zone in petiolule. Therefore the growth regulator probably increased ethylene level at the abscission zone to cause leaflet drop. The symptom agreed with the finding that the growth regulator selectively affected actively dividing cells (Zilkah et al., 1977). Even though the plant was very susceptible to the symptom, it was inconspicuous. Abscission of half of the leaflets of young leaves did not change the appearance of the hedge. The symptom was avoided by spraying the growth regulator before or at the budbreak.
3. Small leaflets of young leaves (Figure 19C): Affected leaflets

Figure 19A. Necrotic spots on young leaves.

Figure 19B. Leaflet drop.

Figure 19C. Small leaflets of young leaves and chlorosis of unexpanded young leaves and the abscission.

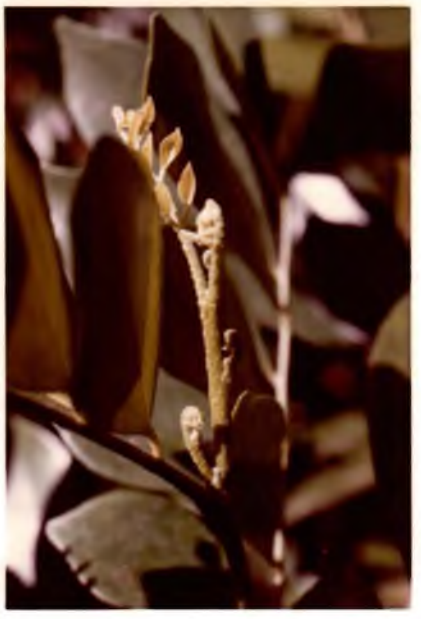
failed to enlarge normally. High concentrations of the growth regulator tended to cause the symptom and early spraying after trimming did not prevent it. The symptom was persistent and conspicuous and was usually accompanied by short internodes.

4. Yellowing of young leaves (Figure 19D): Expanding young leaves did not develop normal green color. The symptom appeared soon after spraying and early spraying caused more incidence. A normal green color eventually developed at maturity.
5. Chlorosis of unexpanded young leaves and abscission (Figure 19C): Developing unexpanded young leaves at the apical meristem showed chlorosis and abscised from the shoot. The symptom only occured with a spray of the growth regulator at expansion of first leaf and showed only in the second flush. Therefore the affected leaves were probably being initiated at the shoot apex at the time of spray. The symptom was not expressed with earlier sprays.
6. Excessive branching (Figure 19E): Three or 4 lateral shoots developed right below the initial cut while 1 to 2 lateral shoots developed normally. The symptom was persistent. Spraying of the growth regulator at expansion of first leaf caused more incidence and early spraying prevented it. The symptom was not harmful to the hedge but could increase the quality by increasing the number of shoots in the hedge.
7. Growth of lateral buds on new shoots (Figure 19F): Dormant lateral buds on the first flush started to grow as the second flush began elongating when the plots were sprayed at expansion of first leaf, but this did not occur with early sprayings. The mechanism could be similar to excessive branching.

Figure 19D. Yellowing of young leaves.

Figure 19E. Excessive branching.

Figure 19F. Growth of lateral buds on new shoot.



These symptoms were rated as 1 to 3 according to the severity at the time of the data collection to get abnormal symptom indexes. The rating was subjective, but the basic idea was to relate concentrations of the spray of the growth regulator and severity of the symptoms on the plant. The criteria for each symptom are listed on Appendix Table 13. Since a purpose of these experiments was to find the most effective concentration which would not change the appearance of the hedge from a short distance, an index rating of 3 could still be acceptable for a distant landscape such as plantings along freeways.

Abnormal symptom indexes (Table 6) were calculated from the ratings of individual plots by the following equation:

$$\text{Abnormal symptom index} = \frac{\Sigma(\text{ratings} \times \text{number of plots which contributed})}{\text{Total number of plots}}$$

Unlike growth suppression, development of abnormal symptoms was very sensitive to the stage of shoot growth at the time of spray. Typical symptoms for the sprays at trimming and budbreak were small leaflets and yellowing of young leaves. If slightly abnormal symptoms were tolerated (symbol 1 in Table 6) 6,000 ppm of the growth regulator could be sprayed. If moderately abnormal symptoms were tolerated for the first 8 weeks (symbol 2), 8,000 ppm could be used. On the other hand, leaves sprayed at first leaf expansion were susceptible to necrotic spots and leaflet drop of young leaves. If slightly abnormal symptoms were tolerated (symbol 1) only 2,000 ppm could be sprayed in spring. There was no difference between full-sun and shade, but full-sun in winter was less sensitive than in spring.

Table 6

Abnormal symptoms of mockorange hedge sprayed with dikegulac-sodium[1]

Season		Spring																Winter				
Light		Full-sun										Shade						Full-sun				
Spray at		Trimming						Budbreak						Expansion				Expansion				
		ppm($x10^3$)						ppm($x10^3$)						ppm($x10^3$)				ppm($x10^3$)				
Abnormal symptom	Week	0	2	4	6	8		0	2	4	6	8		0	2	4	6	8		0	2	4	6	8
Necrotic spots on young leaves	4	.	.	.	.	0		.	.	.	.	.		.	0	2	2	2		.	.	2	1	2		.	0	0	1	1
	8	.	.	.	.	.		.	.	.	.	.		.	.	1	1	2		.	0	1	2	1		.	.	.	.	.
	12	.	.	.	.	.		.	.	.	.	.		.	.	.	.	.		.	.	.	.	.		-	-	-	-	-
Leaflet drop of young leaves	4	.	.	.	.	.		.	.	.	.	.		.	.	.	2	2		.	0	1	2	3		.	.	1	2	2
	8	.	.	.	.	.		.	.	.	.	.		.	.	0	2	1		.	.	0	2	2		.	.	0	1	2
	12	.	.	.	.	.		.	.	.	.	.		.	.	0	.	.		.	.	.	.	.		-	-	-	-	-
Small leaflets of young leaves	4	.	.	.	0	1		.	.	.	1	2		.	.	0	1	1		.	.	0	1	1		.	.	0	1	1
	8	.	.	.	.	1		.	.	.	.	1		.	.	.	0	1		.	.	0	1	0		.	.	.	2	2
	12	.	.	0	.	.		.	.	.	.	0		.	.	.	0	1		.	.	0	2	1		-	-	-	-	-
Yellow of young leaves	4	.	.	.	1	1		.	0	0	1	2		.	.	0	0	1		.	.	1	1	1		.	.	.	1	1
	8	.	0	0	1	2		.	.	.	0	1		.	.	.	.	.		.	.	.	.	.		.	.	.	1	1
	12	.	.	.	.	.		.	.	.	.	.		.	.	.	.	.		.	.	.	.	.		-	-	-	-	-
Chlorosis of leaf primordia and the abscission	4	.	.	.	.	.		.	.	.	.	.		.	.	.	.	.		.	.	.	.	.		.	.	.	.	.
	8	.	.	.	.	.		.	.	.	.	.		.	.	0	0	1		.	.	.	0	0		.	.	.	.	1
	12	.	.	.	.	.		.	.	.	.	.		.	.	0	0	2		.	.	0	1	0		-	-	-	-	-
Excessive branching	4	.	.	.	.	.		.	.	.	0	1		.	.	1	1	2		.	.	.	.	.		.	.	.	.	.
	8	.	.	.	.	.		.	.	.	.	.		.	.	1	1	1		.	.	.	1	0		.	.	.	.	.
	12	.	.	.	.	.		.	.	.	.			.	.	.	0	0		.	.	.	.	.		-	-	-	-	-
Growth of lateral buds on young shoots	4	.	.	.	.	.		.	.	.	.	.		.	.	.	.	.		.	.	.	.	.		.	.	0	0	0
	8	.	.	.	.	.		.	.	.	.	.		.	.	1	0	1		.	.	0	0	.		1	1	1	1	1
	12	.	.	.	0	1		.	.	.	.	.		.	.	1	2	2		.	.	.	0	.		-	-	-	-	-

[1]Symbols for abnormal symptom index were:

. for abnormal symptom index = 0
0 for 0 < abnormal symptom index < 0.5
1 for 0.5 ≦ abnormal symptom index < 1.0
2 for 1.0 ≦ abnormal symptom index < 2.0
3 for 2.0 ≦ abnormal symptom index

In general, the early sprays inhibited the normal development of young leaves in the first flush and the late spray inhibited normal development of shoots and leaves in the second flush. The evidence indicated that the growth regulator selectively inhibited the cell division at apical meristem and that the plant parts which showed abnormal symptoms were actively dividing at the time of spray.

Effectiveness of dikegulac-sodium as a growth retardant for mockorange hedge.

There is not a standardized method of evaluating the effectiveness of growth retardants on growth. Units of growth could include length, area, volume, or weight. Comparisons could be done using means, medians, range of response or model classes. Inhibition could be expressed as percentages or differences. An economic measure of effectiveness of a growth retardant for a hedge could be determined by the ability to delay trimmings because the number of trimmings in a given growth period determines the economics of maintenance.

The growth of mockorange responded almost linearly to dikegulac-sodium within the range 0 to 8,000 ppm. Therefore linear regressions were taken on each set of observations of experiment II. The regression lines are shown in Appendix Figure 3 and the coefficients are listed in Appendix Table 14.

The delay of growth in weeks for a given spray concentration and weeks after spray is drawn from Appendix Figure 3 and shown in Table 7. The number in the table represents number of weeks for control shoots after treatment which gave the same level of elongation as the treated shoots. The table could be used to determine an appropriate spray concentration. For example, if the hedge were trimmed every 4 weeks and

Table 7

Delay of growth of mockorange hedge in weeks caused by dikegulac-sodium in experiment III

Weeks after spring	Control growth in weeks which resulted the same elongation as sprayed shoots											
	Sprayed at trimming				Sprayed at budbreak				Sprayed at expansion of first leaf			
	ppm($x10^3$)				ppm($x10^3$)				ppm($x10^3$)			
	2	4	6	8	2	4	6	8	2	4	6	8
2	2	2	2	2	2	2	2	2	2	2	2	2
4	4	4	4	4	2	2	2	2	4	2	2	2
6	4	4	4	4	6	6	6	2	4	2	2	2
8	8	8	4	4	8	6	6	6	6	4	2	2
10	8	8	4	4	8	6	6	6	6	4	2	2
12	10	8	8	4	8	6	6	6	6	4	2	2
14	10	8	8	4	8	6	6	6	6	4	2	2

sprayed with the growth regulator right after trimming, 2,000 ppm and 4,000 ppm of the spray extends the frequency of trimming to 6 weeks, 6,000 ppm to 10 weeks, and 8,000 ppm to more than 14 weeks.

The delay of trimming was largely caused by the dormancy period at the end of second flush, therefore it would be interesting to see the growth pattern if the third flush occurred.

Table 7 could be used with the following considerations for the effective growth regulation of mockorange hedge:

1. Abnormal symptoms showed at all concentrations; therefore Table 6 should always be consulted to find a proper concentration for safe use of the growth regulator. The reduction of the hedge growth was observed to a greater degree than presented in this paper because the treatment usually caused small young leaves and the visual impression of height was judged from the sum of shoot length and leaf length rather than shoot length only.
2. Sprays at different stages of growth caused different abnormal symptoms in the first and second flushes and probably would cause differences in the third flush. Regrowth of mockorange was sensitive to both seasons and the growth regulator. The treatment was not needed in September and October when plants did not show regrowth and the growth regulator effectively reduced regrowth in spring but not in winter.
3. Shade would be regarded equal to a spray of 2,000 ppm of the growth regulator in spring, but the effect was not additive.
4. The growth within the hedge was different; the center part of the hedge grew taller than the part close to the edge, some fast growing shoots occurred at the edge, and north side and south side grew

differently.

5. Strength of apical dominance could affect the effectiveness of the growth regulator. When the growth conditions are not optimal there would be a strong competition for metabolites by the shoots and strong apical dominance would result. Since the growth regulator was effective on actively dividing cells, the dominant shoot could be suppressed, and another lateral shoot replace it. When the growth conditions were optimal there would be enough metabolites so that many lateral shoots could be active. The growth regulator would effectively suppress the growth on all actively growing shoots.

Suggestions for the future experiment

1. Use of dikegulac-sodium with other growth regulators such as gibberellic acid synthesis inhibitors could be effective since the latter could suppress the first flush while the former suppresses the second flush.
2. Multiple applications of the growth regulator could decrease abnormal symptoms and also increase growth retardation because less concentration would be used at one application and the growth regulator could be effective for longer time than single application.
3. Residual effects of the growth regulator should be studied since the hedge should be existent for long time, and the treatment would be frequent over the years.
4. A study of growth characteristics such as flushings and growth rate and morphology of developing apical buds such as number of leaf primordia at apices would clear the mechanism of action of the growth regulator in mockorange and lead to the effective use.

5. It is desirable to determine the economics of maintenance of mockorange hedge to find if the use of dikegulac-sodium would reduce the cost, and if it would, by how much. The frequency of trimming and spraying necessary for one growing season and cost for both trimming and the growth regulator application should be studied.

SUMMARY

1. Frequency distribution of lateral shoots of mockorange was log normal.
2. Sampling of the longest lateral shoot from each plot represented height of the hedge better than random sampling of lateral shoots.
3. Lateral shoots of mockorange showed 2 flushes in 18 weeks.
4. Dikegulac-sodium effectively suppressed the growth of mockorange in spring but not in winter.
5. Spraying dikegulac-sodium at different stages of growth did not cause differences in growth suppression.
6. The effect of shade was equivalent to the spray of 2,000 ppm of dikegulac-sodium in spring.
7. Vigor of mockorange did not change the effectiveness of dikegulac-sodium in winter.
8. Absorption of dikegulac-sodium was fast and the amount absorbed after one-half hour was enough to reduce the growth of dominant shoot in saran house.
9. Dikegulac-sodium with 2,000 to 8,000 ppm effectively delayed the regrowth of lateral shoots without causing unacceptable abnormal symptoms.

Appendix Table 1

Analysis of variance for testing uniformity of growth of two hedges in Waimanalo[1]

Source of variation	Degrees of freedom	Sum of squares	Mean square	F[2]
Between hedges	1	8.41634	8.41634	67.03**
Between plants within hedges	10	10.20742	1.02074	8.13**
Between sides within plants	12	4.86821	0.40568	3.23**
Within sides	192	24.10860	0.12557	
Total	215	47.60056		

[1]The original data were transformed as log (X+1).

[2]**: significant at 5% level. c.v. was 25.9%

Appendix Table 2. -- Analysis of variance for comparing two growth regulators in Waimanalo at 8 and 14 weeks after the treatment[1]

Source of variation	Degrees of freedom	Mean square		F[2]	
		8 weeks	14 weeks	8 weeks	14 weeks
Treatments	(8)				
Control vs. growth regulators	1	0.24883	0.00574	1.61$^{n.s.}$	0.15$^{n.s.}$
Dikegulac-sodium vs. Krenite[3]	1	0.89433	0.06219	5.77**	1.62$^{n.s.}$
Others	6	0.13510	0.07262	0.87$^{n.s.}$	1.90*
Between plants within treatments	9	0.14877	0.06779	0.96$^{n.s.}$	1.77*
Within plants	144	0.15482	0.03832		
Total	161				

[1]The original data were transformed as log (X+1).

[2]n.s.: not significant. *: significant at 10% level. **: significant at 5% level. c.v. for 8 weeks was 32.4%. c.v. for 14 weeks was 13.3%.

[3]Ammonium ethyl carbamoylphosphonate.

Appendix Table 3. -- Analysis of variance for comparison of growth at two positions, outer plots and inner plots, on the Kuykendall hedge at 10 weeks after spray in November 1979[1]

Source of variance	Degrees of freedom	Sum of square	Mean square	F[2]
Between pairs	4	6.35793		
Between sides	1	2.24565	2.24565	2.72[n.s.]
Between pairs within sides	3	4.11228	1.37076	1.66[n.s.]
Within pairs	85	79.40983		
Between positions within pairs	5	13.31922	2.66385	3.22*
Within positions	80	66.09062	0.82613	
Total	89	85.76776		

[1]The original data were transformed as log (X+1).

[2]n.s.: not significant. *: significant at 5% level. c.v. was 29.9%.

Appendix Table 4. -- Analysis of variance for the effect of dikegulac-sodium sprays in November 1979 and the sides of the hedge at Kuykendall Hall at 10 weeks after the sprays

Source of variance	Degrees of freedom	Mean square	F[2]
Between treatments	9	0.19804	2.17**
Sides (north vs. south)	1	0.53026	5.81**
Concentrations - linear	1	0.35307	3.87*
Concentrations - quadratic	1	0.07571	0.83 n.s.
Concentrations - cubic	1	0.36756	4.02**
Concentrations - quartic	1	0.06660	0.72 n.s.
Sides x concentrations - linear	1	0.00458	0.05 n.s.
Sides x concentrations - quadratic	1	0.36452	3.80*
Sides x concentrations - cubic	1	0.00837	0.09 n.s.
Sides x concentrations - quartic	1	0.01169	0.13 n.s.
Plots within treatments	15	0.32611	3.57**
Within plots (error)	150	0.09125	
Total	174		

[1]The original data were transformed as log (X+1).

[2]**: significant at 5% level. *: significant at 10% level. n.s.: not significant. c.v. was 21.6%.

Appendix Table 5. -- Analysis of variance for testing the effect of dikegulac-sodium on the longest shoots at 8 weeks after the sprays in winter 1980 and spring 1980[1]

Source of variance	Degrees of freedom	Mean square		F^2	
		spring	winter	spring	winter
Sides	1	0.01915	0.07722	$0.26^{n.s.}$	$1.66^{n.s.}$
Replications	2	0.30906	0.05021	5.75*	$1.05^{n.s.}$
Side x replications	2	(0.01880)	(0.01206)		
Concentrations	4	0.99179	0.07029	13.13**	$1.21^{n.s.}$
Concentrations x replications	8	0.07551	0.05790		
Concentrations x sides	4	0.09247	0.03691	$0.78^{n.s.}$	$1.03^{n.s.}$
Concentrations x sides x replications	8	0.02946	0.03577		
Total	29				

[1]The original data were transformed as ln (X).

[2]n.s.: not significant. *: significant at 5% level. **: significant at 1% level. c.v. for concentration for spring and winter were 5.6% and 4.8% respectively.

Appendix Table 6. -- Analysis of variance for testing the effect of dikegulac-sodium on the randomly sampled shoots at 8 weeks after the sprays in spring 1980 and winter 1980[1]

Source of variance	Degrees of freedom	Mean square		F^2	
		spring	winter	spring	winter
Sides	1	0.00962	0.28217	$0.21^{n.s.}$	4.09^{**}
Replications	2	0.95042	0.08216	23.99^{**}	$1.18^{n.s.}$
Sides x replication	2	(0.04265)	(0.11725)		
Concentrations	4	0.29219	0.05823	15.56^{**}	$0.90^{n.s.}$
Concentrations x replications	8	0.01878	0.06458		
Concentrations x sides	4	0.01510	0.09677	$0.21^{n.s.}$	$0.88^{n.s.}$
Concentrations x sides x replications	8	0.07060	0.11002		
Sampling error	240	0.03594	0.06729		
Total	269				

[1]The original data were transformed as log (X).

[2]n.s.: not significant. **: significant at 1% level. c.v. for concentrations for spring and winter were 2.3% and 3.4% respectively.

Appendix Table 7. -- Analysis of variance for comparing stage of growth at the time of spray with dikegulac-sodium on the longest shoots and randomly sampled shoots at 10 weeks after trimming[2]

Source of variance	Degree of freedom		Mean square[2]		F[3]	
	longest	random	longest	random	longest	random
Replications	2	2	0.04750	0.64356	3.46*	13.22**
Sides	1	1	0.00021	0.09427	0.01[n.s.]	1.88[n.s.]
Replications x sides	2	2	(0.00027)	(0.11409)		
Stages	2	2	0.02359	0.20139	1.66[n.s.]	0.89[n.s.]
Replications x stages	4	4	0.01425	0.22562		
Sides x stages	2	2	0.04875	0.43881	2.01[n.s.]	5.04[n.s.]
Replications x sides x stages	4	4	0.02430	0.08712		
Concentrations	4	4	0.10284	0.81754	23.64**	20.09**
Stages x concentrations	8	8	0.00444	0.02457	1.02[n.s.]	0.60[n.s.]
Replications x concentrations (stages)	24	24	0.00435	0.04070		
Others	36	756	0.00947	0.04232		
Total	89	809				

[1]Original data were transformed as log (X).

[2]Longest: one-longest-shoot from each plot. Random: nine-subsampled-shoots.

[3]n.s.: not significant. *: significant at 5% level. **: significant at 1% level. c.v. for concentration were 3.1% for longest and 11.3%.

Appendix Table 8. -- F numbers for concentrations by one-longest-shoots measured biweekly after the sprays of dikegulac-sodium[1]

Stage of growth at the time of spray	F weeks after spray							
	1	2	4	6	8	10	12	14
Trimming	-	3.53$^{n.s.}$	21.1**	24.31**	7.92**	7.70**	8.70**	7.07**
Budbreak	2.58$^{n.s.}$	22.06**	10.99**	6.97**	8.53**	6.39**	5.81**	6.28**
Expansion of first leaf	3.16$^{n.s.}$	7.98**	14.73**	10.42**	26.27**	16.03**	17.95**	18.45**

[1]Error term for concentrations was concentrations x replications.

Appendix Table 9. -- Analysis of variance for comparing effect of shade on plants sprayed with dikegulac-sodium at expansion of first leaf 10 weeks after trimming[1]

Source of variance	Degrees of freedom[2]		Sum of square		Mean square		F[3]	
	longest	random	longest	random	longest	random	longest	random
Between treatments	1	1	0.34574	4.72562	0.34574	4.72562	71.91**	164.98**
Between sides within treatments	2	2	0.03580	0.44508	0.01790	0.02254	3.72*	7.77**
Between concentrations within sides	16	16	0.27113	9.96657	0.01695	0.62291	3.52**	21.75**
Within concentrations	40	520	0.19233	14.89480	0.00481	0.02864		
Total	59	539	0.84500	30.03206				

[1]The original data were transformed as log(X).

[2]Longest: one-longest-shoot from plot. Random: nine-subsampled-shoots.

[3]*: significant at 5% level. **: significant at 1% level. c.v. was 2.4% for longest and 1.6% for random.

Appendix Table 10. -- Comparison of regression lines for the plants sprayed with 4,000 ppm of dikegulac-sodium at expansion of the first leaves

Source of variance	Degrees of freedom	Σx^2	Σxy	Σy^2	Regression coefficient	Deviation from regression d.f.	SS	MS	F^2
Within treatments									
Control	11	15,120	-288	488	-0.019	10	482	48.2	$1.09^{n.s.}$
Treated	47	107,080	-7,173	2,523	-0.067	46	2,042	44.4	
						56	2,524	45.1	
					Difference between slopes	1	31	31.0	$0.69^{n.s.}$
Pooled	58	122,200	-7,461	3,011	-0.061	57	2,555	44.3	
Between treatments	1	12,862	-3,145	769					
					Difference between adjusted means	1	392	392.0	8.85**
Total	59	135,062	-10,606	3,780		58	2,947		

[1]The original data were subjected to arcsine transformation.

[2]n.s.: not significant. **: significant at 1% leve. c.v. for difference between adjusted means was 1.88%.

Appendix Table 11. -- Analysis of variance for the effect of duration for absorption on the lateral shoot development after applying 4,000 ppm dikegulac-sodium at 35 days after pruning

Source of variance	Degrees of freedom	Sum of squares	Mean square	F[1]
Treatments	5	6,762.76	1,352.55	1.83$^{n.s.}$
Position	4	163,705.86	40,926.46	55.26**
Error	170	125,901.71	740.60	
Total	179	296,370.33		

[1] n.s.: not significant. **: significant at 1% level. c.v. was 29.6%.

Appendix Table 12. -- Analysis of variance for the effect of dikegulac-sodium on number of internodes on the first shoots 35 days after prunings

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatments	5	6.56	1.31	$1.73^{n.s.}$
Error	30	22.67	0.76	
Total	35	29.22		

[1]n.s.: not significant. c.v. was 14.3%.

Appendix Table 13

Criteria for rating abnormal symptoms

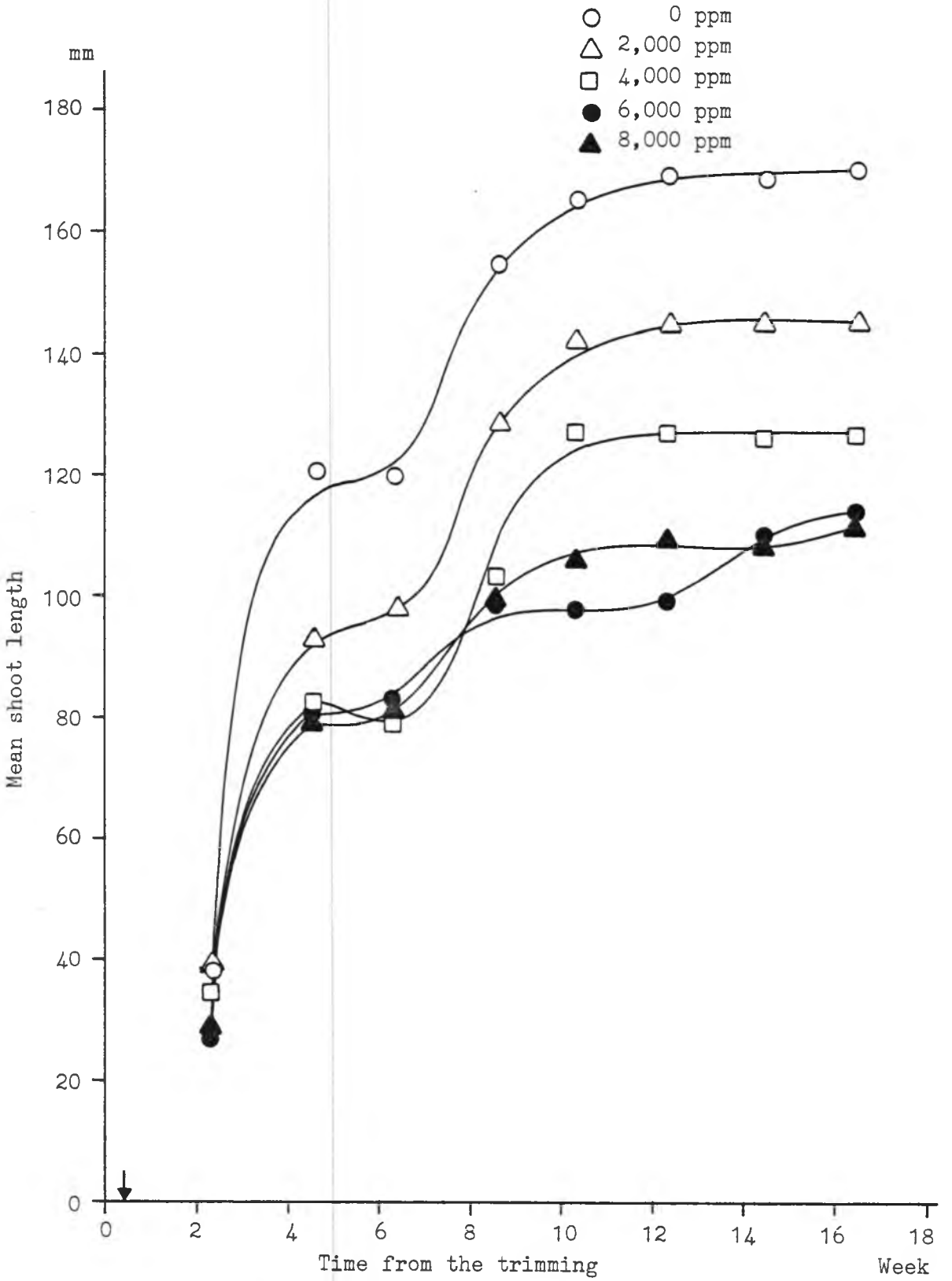
Abnormal symptom	Rating[1]	Description
Necrotic spots young leaves	1	Shows the symptom on few leaflets
	2	Shows the symptom on half of the leaflets
	3	Shows the symptom on most of the leaflets
Leaflet drops of young leaves	1	One or two leaflets drop from a leaf
	2	Half of the leaflets drop from a leaf
	3	All leaflets drop from a leaf
Small leaflets of young leaves	1	Slight
	2	Moderate
	3	Severe
Yellow of young leaves leaves	1	Slight
	2	Moderate
	3	Severe
Chlorosis of leaf buds at shoot apeces	1	Shows the symptom on few shoots
	2	Shows the symptom on half of the shoots
	3	Shows the symptom on most of the shoots
Excessive branching	1	Shows the symptom on few branches
	2	Shows the symptom on half of the branches
	3	Shows the symptom on half of the branches
Growth of lateral buds	1	Shows the symptom on few shoots
	2	Shows the symptom on half of the shoots
	3	Shows the symptom on most of the shoots

[1]If the plant did not show the symptoms then rating of 0 was given.

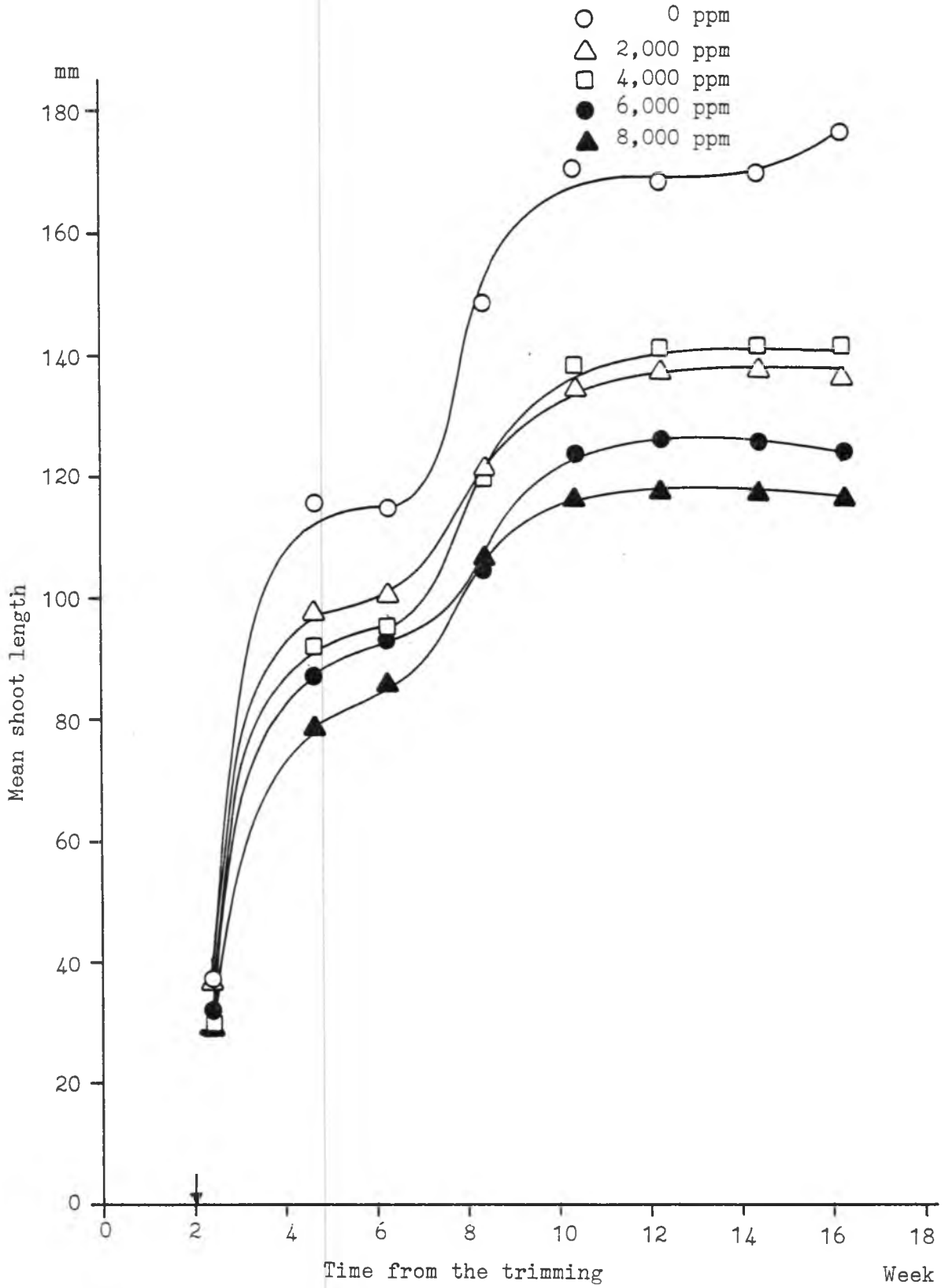
Appendix Table 14

Coefficients for linear regression of on-longest-shoots in experiment II

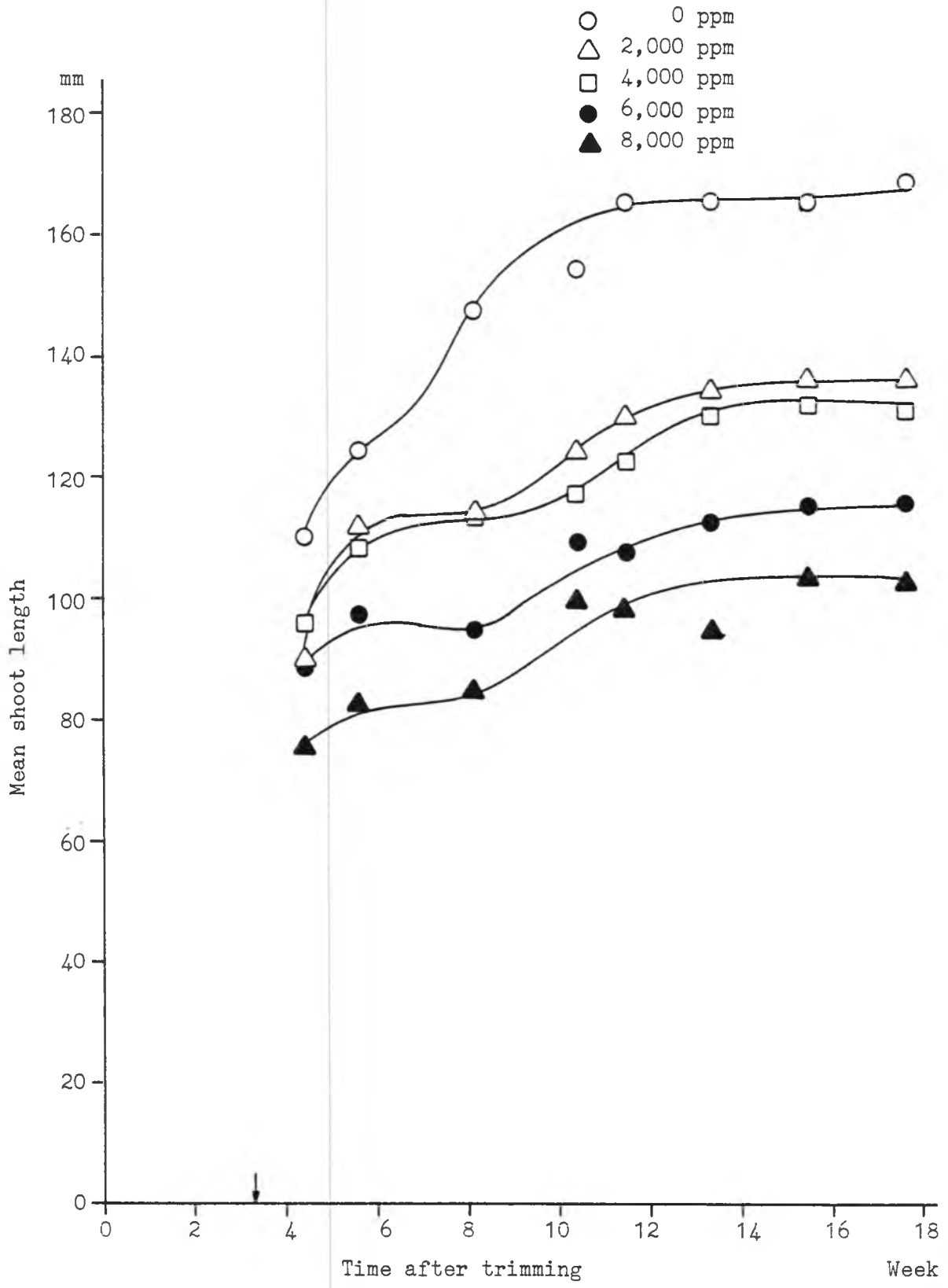
Weeks after spray	Sprayed at trimming		Sprayed at budbreak		Sprayed at expansion of first leaf	
	Correlation coefficient	Slope ($x10^{-3}$)	Correlation coefficient	Slope ($x10^{-3}$)	Correlation coefficient	Slope ($x10^{-3}$)
2	-0.54	-1.6	-0.65	-4.3	-0.70	-5.2
4	-0.69	-4.6	-0.56	-3.4	-0.67	-7.1
6	-0.64	-4.3	-0.47	-5.5	-0.56	-6.8
8	-0.66	-7.2	-0.48	-7.2	-0.63	-8.4
10	-0.66	-8.4	-0.43	-6.3	-0.65	-8.6
12	-0.67	-8.3	-0.44	-6.5	-0.61	-7.9
14	-0.66	-8.0	-0.48	-7.0	-0.58	-7.9



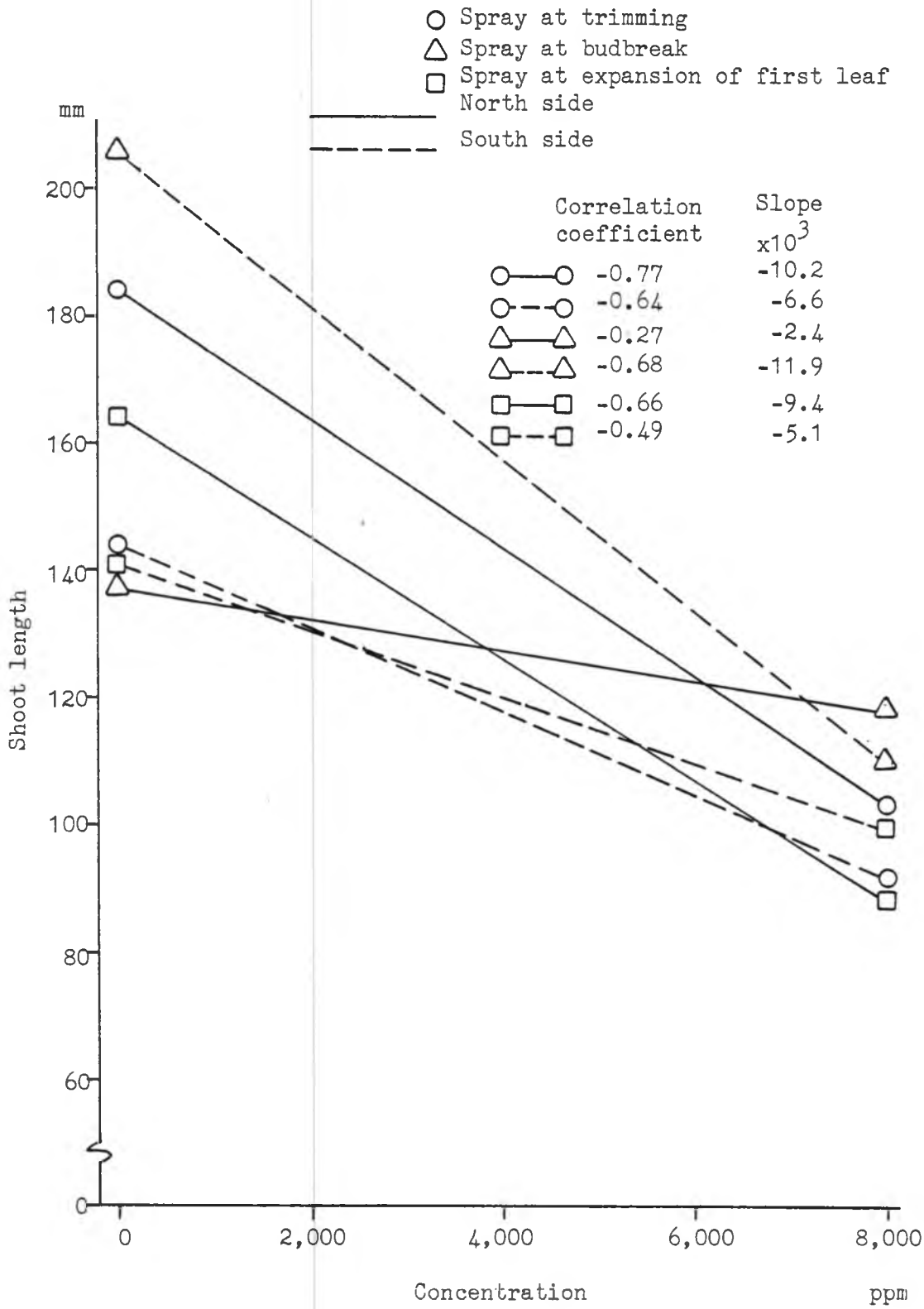
Appendix Figure 1A. Growth of the longest shoots sprayed with dikegulac-sodium at trimming



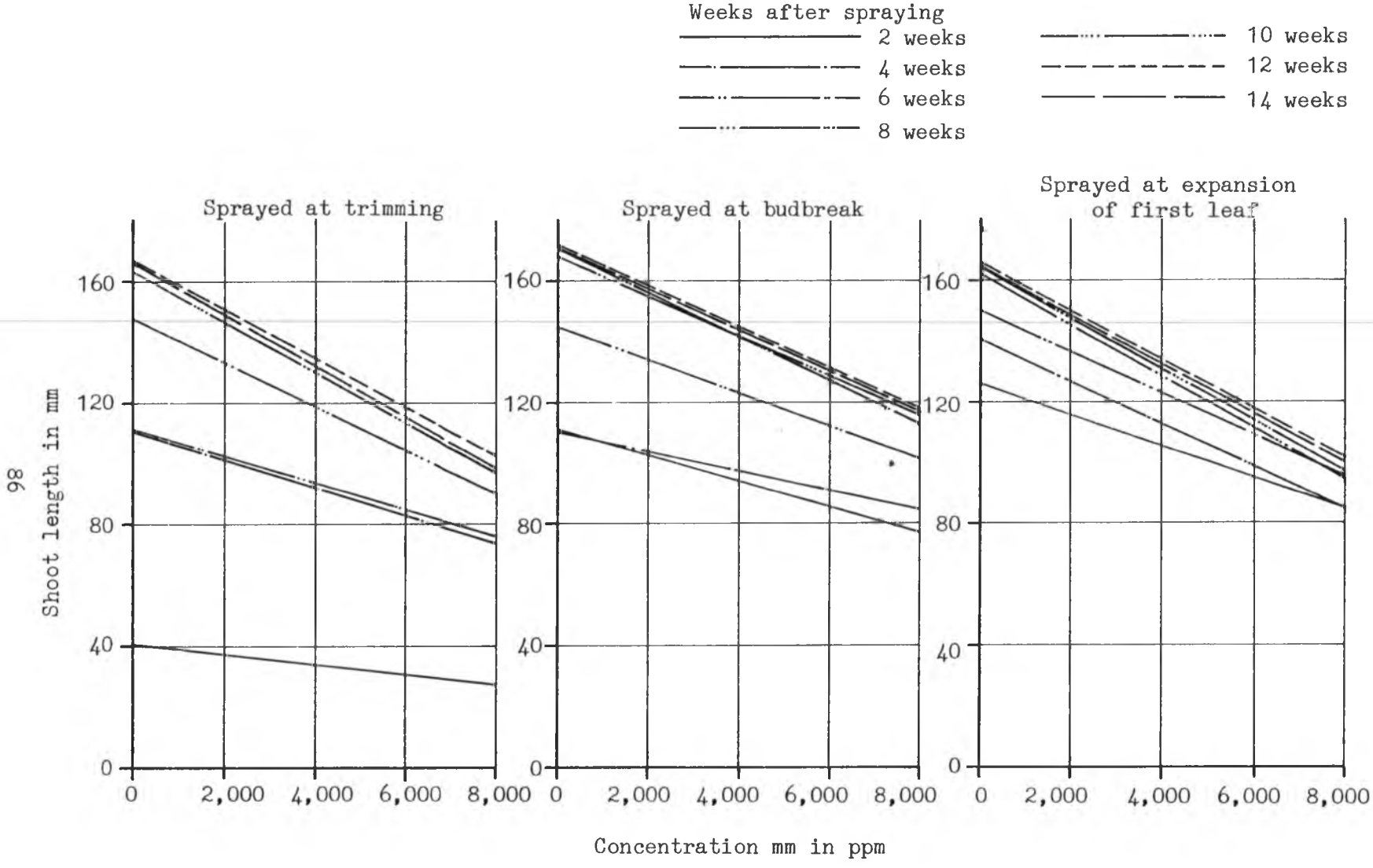
Appendix Figure 1B. Growth of the longest shoots sprayed with dikegulac-sodium at budbreak.



Appendix Figure 1C. Growth of the longest shoots sprayed with dikegulac-sodium at expansion of first leaf.



Appendix Figure 2. Linear regressions of the longest shoots sprayed with dikegulac-sodium 10 weeks after trimming.



Appendix Figure 3. Linear regression lines of the longest shoots sprayed with dikegulac-sodium.

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